



University of  
Zurich<sup>UZH</sup>

Zurich Open Repository and  
Archive

University of Zurich  
University Library  
Strickhofstrasse 39  
CH-8057 Zurich  
[www.zora.uzh.ch](http://www.zora.uzh.ch)

---

Year: 2017

---

## Measurement of $B^\pm$ meson differential production cross sections in pp and PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

CMS Collaboration ; Canelli, Maria Florencia ; Kilminster, Benjamin ; Aarrestad, Thea K ; Caminada, Lea ; De Cosa, Annapaoloa ; Del Burgo, Riccardo ; Donato, Silvio ; Galloni, Camilla ; Hinzmann, Andreas ; Hreus, Tomas ; Ngadiuba, Jennifer ; Pinna, Deborah ; Rauco, Giorgia ; Robmann, Peter ; Salerno, Daniel ; Schweiger, Korbinian ; Seitz, Claudia ; Takahashi, Yuta ; Zucchetta, Alberto ; et al

**Abstract:** The differential production cross sections of  $B^\pm$  mesons are measured via the exclusive decay channels  $B^\pm \rightarrow J\psi K^\pm \rightarrow \mu^+\mu^- K^\pm$  as a function of transverse momentum in  $pp$  and PbPb collisions at a center-of-mass energy  $\sqrt{s_{NN}} = 5.02$  TeV per nucleon pair with the CMS detector at the LHC. The  $pp(PbPb)$  dataset used for this analysis corresponds to an integrated luminosity of  $28.0 \text{ fb}^{-1}$  ( $351 \mu\text{b}^{-1}$ ). The measurement is performed in the  $B^\pm$  meson transverse momentum range of 7 to 50  $\text{GeV}/c$ , in the rapidity interval  $|y| < 2.4$ . In this kinematic range, a strong suppression of the production cross section by about a factor of two is observed in the PbPb system in comparison to the expectation from  $pp$  reference data. These results are compared to theoretical calculations incorporating beauty quark diffusion and energy loss in a quark-gluon plasma.

DOI: <https://doi.org/10.1103/PhysRevLett.119.152301>

Posted at the Zurich Open Repository and Archive, University of Zurich

ZORA URL: <https://doi.org/10.5167/uzh-140717>

Journal Article

Published Version



The following work is licensed under a Creative Commons: Attribution 4.0 International (CC BY 4.0) License.

Originally published at:

CMS Collaboration; Canelli, Maria Florencia; Kilminster, Benjamin; Aarrestad, Thea K; Caminada, Lea; De Cosa, Annapaoloa; Del Burgo, Riccardo; Donato, Silvio; Galloni, Camilla; Hinzmann, Andreas; Hreus, Tomas; Ngadiuba, Jennifer; Pinna, Deborah; Rauco, Giorgia; Robmann, Peter; Salerno, Daniel; Schweiger, Korbinian; Seitz, Claudia; Takahashi, Yuta; Zucchetta, Alberto; et al (2017). Measurement of  $B^\pm$  meson differential production cross sections in pp and PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. Physical Review Letters, 119:152301.

DOI: <https://doi.org/10.1103/PhysRevLett.119.152301>

# Measurement of the $B^\pm$ Meson Nuclear Modification Factor in Pb-Pb Collisions at $\sqrt{s_{NN}} = 5.02$ TeV

A. M. Sirunyan *et al.*\*

(CMS Collaboration)

(Received 12 May 2017; revised manuscript received 1 September 2017; published 13 October 2017)

The differential production cross sections of  $B^\pm$  mesons are measured via the exclusive decay channels  $B^\pm \rightarrow J/\psi K^\pm \rightarrow \mu^+ \mu^- K^\pm$  as a function of transverse momentum in  $pp$  and Pb-Pb collisions at a center-of-mass energy  $\sqrt{s_{NN}} = 5.02$  TeV per nucleon pair with the CMS detector at the LHC. The  $pp$ (Pb-Pb) data set used for this analysis corresponds to an integrated luminosity of  $28.0 \text{ pb}^{-1}$  ( $351 \mu\text{b}^{-1}$ ). The measurement is performed in the  $B^\pm$  meson transverse momentum range of 7 to 50 GeV/ $c$ , in the rapidity interval  $|y| < 2.4$ . In this kinematic range, a strong suppression of the production cross section by about a factor of 2 is observed in the Pb-Pb system in comparison to the expectation from  $pp$  reference data. These results are found to be roughly compatible with theoretical calculations incorporating beauty quark diffusion and energy loss in a quark-gluon plasma.

DOI: 10.1103/PhysRevLett.119.152301

Relativistic heavy ion collisions allow the study of quantum chromodynamics (QCD) at high energy density. Under such extreme conditions, a state consisting of deconfined quarks and gluons, the quark-gluon plasma (QGP) [1,2], is predicted by lattice QCD calculations [3]. Hard-scattered partons are expected to lose energy via elastic collisions and medium-induced gluon radiation as they traverse the QGP. This phenomenon, known as jet quenching [4–7], results in the suppression of the yield of high transverse momentum ( $p_T$ ) hadrons, compared to the expectation based on proton-proton ( $pp$ ) data, in which the outgoing partons traverse the QCD vacuum. Measurements of the jet quenching dependence on the type of initiating parton (both quark vs gluon and light vs heavy quarks) are key to constrain the QGP properties [8–12].

The production of  $B$  mesons was studied at the Large Hadron Collider (LHC) in  $pp$  collisions at center-of-mass energies of  $\sqrt{s} = 7$  [13–19], 8 [20,21] and 13 TeV [22] over wide  $p_T$  and rapidity ( $y$ ) intervals, and in proton-lead ( $p\text{Pb}$ ) collisions at a center-of-mass energy per nucleon pair  $\sqrt{s_{NN}} = 5.02$  TeV [23]. The CMS Collaboration also measured the nonprompt (i.e., from decays of  $b$  hadrons)  $J/\psi$  meson production in lead-lead (Pb-Pb) and  $pp$  collisions at  $\sqrt{s_{NN}} = 2.76$  TeV [24]. For nonprompt  $J/\psi$ , a strong suppression was observed in the nuclear modification factor  $R_{AA}$ , the ratio of the nonprompt  $J/\psi$  cross section in Pb-Pb collisions with respect to that in  $pp$

collisions scaled by the number of binary nucleon-nucleon ( $NN$ ) collisions. In this Letter, we extend the study of heavy-quark production by performing the first measurement of exclusive  $B^\pm$  meson decays in Pb-Pb collisions. This provides direct information about the  $b$  hadron kinematics and flavor content, compared to the measurements of nonprompt  $J/\psi$ , which are decay products of various beauty mesons and baryons.

The  $B^\pm$  mesons are measured in the interval  $|y| < 2.4$  and in five  $p_T$  bins ([7, 10], [10, 15], [15, 20], [20, 30], [30, 50] GeV/ $c$ ), via the reconstruction of the decay channels  $B^\pm \rightarrow J/\psi K^\pm \rightarrow \mu^+ \mu^- K^\pm$ , which have the branching fraction  $\mathcal{B} = (6.12 \pm 0.19) \times 10^{-5}$  [25]. Throughout the Letter, unless otherwise specified, the  $y$  and  $p_T$  variables given are those of the  $B^\pm$  mesons. This analysis does not distinguish between the charge conjugates.

The central feature of the CMS detector is a superconducting solenoid that provides a magnetic field of 3.8 T. Within the solenoid volume are a silicon tracker, which measures charged particles within the pseudorapidity range  $|\eta| < 2.5$ , a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter. For typical particles of  $1 < p_T < 10$  GeV/ $c$  and  $|\eta| < 1.4$ , the track resolutions are typically 1.5% in  $p_T$  and 25–90 (45–150)  $\mu\text{m}$  in the transverse (longitudinal) impact parameter [26]. Muons are measured in the range  $|\eta| < 2.4$ , with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. The muon reconstruction algorithm starts by finding tracks in the muon detectors, which are then fitted together with tracks reconstructed in the silicon tracker to form “global muons.” Matching muons to tracks measured in the silicon tracker results in a relative  $p_T$  resolution for muons with  $20 < p_T < 100$  GeV/ $c$  of 1.3–2.0% in the barrel ( $|\eta| < 1.2$ ) and better than 6% in the end caps ( $1.6 < |\eta| < 2.4$ ). For muons with

\*Full author list given at the end of the article.

Published by the American Physical Society under the terms of the Creative Commons Attribution 4.0 International license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

higher  $p_T$  up to 1 TeV/ $c$ , the  $p_T$  resolution in the barrel is better than 10% [27]. The hadron forward (HF) calorimeter uses steel as an absorber and quartz fibers as the sensitive material. The two halves of the HF are located 11.2 m away from the interaction point, one on each end, providing together coverage in the range  $3.0 < |\eta| < 5.2$ . In this analysis, the HF information is used for performing an offline event selection. A detailed description of the CMS experiment and coordinate system can be found in Ref. [28].

For the decay channel measured in this analysis, the background consists primarily of two sources. A combinatorial background originates from randomly pairing a  $J/\psi$  with an unrelated charged particle. This gives rise to a falling contribution in the invariant mass spectrum. A heightened background in the invariant mass region below 5.4 GeV/ $c^2$  is also present, which corresponds to partially reconstructed  $b$  hadron decays from processes other than the one of interest. As an example, a heightened structure can be created by  $B^0 \rightarrow J/\psi K^*(892)^0 \rightarrow \mu^+\mu^-K^+\pi^-$  [ $\bar{B}^0 \rightarrow J/\psi \bar{K}^*(892)^0 \rightarrow \mu^+\mu^-K^-\pi^+$ ] decays in which one decay product is lost, resulting in a  $B^+$  ( $B^-$ ) candidate. Several Monte Carlo (MC) simulated event samples are used to evaluate background components, signal efficiencies and detector acceptance corrections. This includes samples containing only the  $B^\pm$  meson decays channels being measured, and samples with inclusive (prompt and nonprompt)  $J/\psi$  mesons. Proton-proton collisions are generated with PYTHIA 8 [29] tune CUETP8M1 [30] and propagated through the CMS detector using the GEANT4 package [31]. The decay of the  $B$  mesons is modeled with the EVTGEN 1.3.0 [32], and final-state photon radiation in the  $B$  decays is simulated with PHOTOS 2.0 [33]. For the Pb-Pb MC samples, each PYTHIA 8 event is embedded into a Pb-Pb collision event generated with HYDJET 1.8 [34], which is tuned to reproduce global event properties, such as the charged-hadron  $p_T$  spectrum and particle multiplicity.

Events were collected with the same trigger during the  $pp$  and Pb-Pb data taking, requiring the presence of two muon candidates, with no explicit momentum threshold. For the offline analysis, events have to pass a set of selection criteria designed to reject events from background processes (beam-gas collisions and beam scraping events) as described in Ref. [35]. Events are required to have at least one reconstructed primary interaction vertex with a distance from the center of the nominal interaction region of less than 15 cm along the beam axis. In Pb-Pb collisions, the shapes of the clusters in the pixel detector have to be compatible with those expected from particles produced by a Pb-Pb collision [36]. The Pb-Pb collision event is also required to have at least three towers in each of the HF detectors with energy deposits of more than 3 GeV per tower. These criteria select  $(99 \pm 2)\%$  of inelastic hadronic Pb-Pb collisions. Selection efficiencies higher than 100% are possible, reflecting the possible presence of

ultraperipheral (i.e., nonhadronic) collisions in the selected event sample. The Pb-Pb sample corresponds to an integrated luminosity of approximately  $351 \mu\text{b}^{-1}$ . This value is indicative only, as the Pb-Pb yield is normalized by the total number of minimum-bias events sampled,  $N_{\text{MB}}$ . The  $pp$  data set corresponds to an integrated luminosity of  $28.0 \text{ pb}^{-1}$ , which is known to an accuracy of 2.3% from the uncertainty in the calibration based on a van der Meer scan [37].

Kinematic limits are imposed on the single muons so that their reconstruction efficiency stays above 10%. These limits are  $p_T^\mu > 3.5 \text{ GeV}/c$  for  $|\eta^\mu| < 1.2$ ,  $p_T^\mu > 1.8 \text{ GeV}/c$  for  $2.1 \leq |\eta^\mu| < 2.4$ , and linearly interpolated in the intermediate  $|\eta^\mu|$  region. The muons are also required to match the muons that triggered the event online, and pass selection criteria optimized for low  $p_T$  (the so-called soft selection [27]). Two muons of opposite charge with an invariant mass within 150 MeV/ $c^2$  of the world-average  $J/\psi$  meson mass [25] are selected to reconstruct a  $J/\psi$  candidate, with a mass resolution of typically 18–55 MeV/ $c^2$ , degrading as a function of the dimuon rapidity and  $p_T$ . Opposite-sign muon pairs are fitted with a common vertex constraint and are kept if the  $\chi^2$  probability of the fit is greater than 1%, lowering the background from charm- and beauty-hadron semileptonic decays. Each  $B$  meson candidate is formed from the combination of a  $J/\psi$  candidate with a charged-particle track, which are required to pass standard selections described in Ref. [35]. Without using particle identification, assumptions need to be made about the masses of the charged particles. In calculating the mass of the  $B^\pm$  candidates, the single charged particle is always assumed to have the mass of a charged kaon, and the muon pair is assumed to have the mass of a  $J/\psi$  meson. A single-track low- $p_T$  threshold of 0.5 GeV/ $c$  for  $pp$  collisions and 0.8 GeV/ $c$  for Pb-Pb collisions is applied to reduce the combinatorial background, which is further minimized by additional selection criteria. In particular,  $B^\pm$  candidates are selected according to the  $\chi^2$  probability of their decay vertex (the probability for the muon tracks from the  $J/\psi$  meson decay and the other charged track to point to a common vertex), the three-dimensional (3D) flight distance (normalized by its uncertainty) between the primary and decay vertices, and the pointing angle, which is defined as the angle between the line segment connecting the primary and decay vertices and the momentum vector of the  $B^\pm$  meson in the plane transverse to the beam direction. The selection is optimized in each  $p_T$  bin, separately for  $pp$  and Pb-Pb results, using a multivariate technique that utilizes the genetics algorithm [38], in order to maximize the statistical significance of the  $B^\pm$  mesons signal.

The raw yields of  $B^\pm$  mesons in  $pp$  and Pb-Pb collisions are extracted using a binned maximum likelihood fit to the  $B^\pm$  meson invariant mass distributions in the mass range 5–6 GeV/ $c^2$ . The estimation of the statistical uncertainties

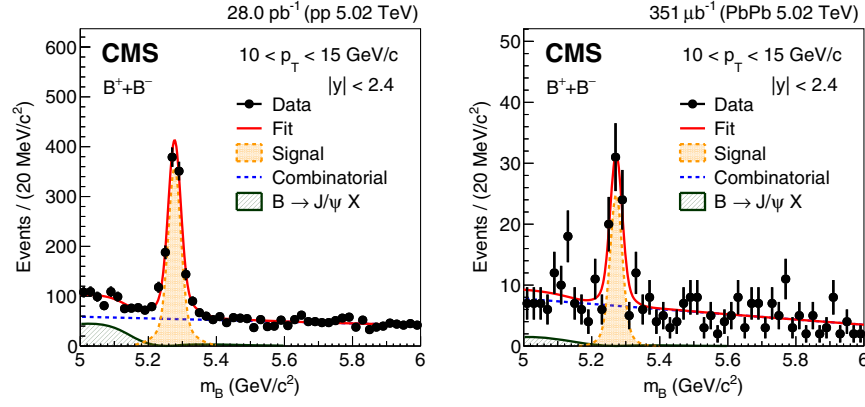


FIG. 1. Invariant mass distributions of  $B^\pm$  candidates in  $pp$  (left) and Pb-Pb (right) collisions measured in  $|y| < 2.4$  and in the  $p_T$  region 10–15 GeV/c.

of the fitted raw yields is based on the second derivatives of the negative log-likelihood function. Examples of fits to the invariant mass distributions in  $pp$  and Pb-Pb collisions are shown in Fig. 1, for the  $p_T$  region 10–15 GeV/c. The signal shape is modeled by two Gaussian functions with a common mean, a free parameter of the fit, and different widths determined from MC simulation for each  $p_T$  bin, individually for the  $pp$  and Pb-Pb results. The relative contribution of the two Gaussian functions to the signal yield is also fixed at the value given by the MC sample. The combinatorial background is modeled by a first-order polynomial as determined by studies of the inclusive  $J/\psi$  MC sample. The peaking background, labeled  $B \rightarrow J/\psi X$  in Fig. 1, is studied with the embedded MC sample including all  $B$  meson decays into final states with a  $J/\psi$  meson and found to be well described by the superposition of a double-sided Gaussian function and an error function. The shape is determined from a fit of the MC sample with all parameters free. The resulting functional form, with the overall normalization left floating, is included in the global fit function.

The differential cross section for  $B^\pm$  production in  $|y| < 2.4$  is computed in each  $p_T$  interval according to

$$\left. \frac{d\sigma^{B^\pm}}{dp_T} \right|_{|y|<2.4} = \frac{1}{2} \frac{1}{\mathcal{B}\mathcal{L}} \frac{1}{\Delta p_T} \frac{N_{pp}^{(B^++B^-)}(p_T)}{\alpha_{pp}(p_T)\epsilon_{pp}(p_T)} \Big|_{|y|<2.4} \quad (1)$$

for  $pp$  data, and for Pb-Pb data according to

$$\begin{aligned} \left. \frac{1}{T_{AA}} \frac{dN_{Pb-Pb}^{B^\pm}}{dp_T} \right|_{|y|<2.4} &= \frac{1}{2} \frac{1}{\mathcal{B}N_{MB}T_{AA}} \frac{1}{\Delta p_T} \frac{N_{Pb-Pb}^{(B^++B^-)}(p_T)}{\alpha_{Pb-Pb}(p_T)\epsilon_{Pb-Pb}(p_T)} \Big|_{|y|<2.4}. \end{aligned} \quad (2)$$

The  $N_{pp,Pb-Pb}^{(B^++B^-)}$  is the raw signal yield extracted in each  $p_T$  interval of width  $\Delta p_T$ ,  $(\alpha\epsilon)_{pp,Pb-Pb}$  represents the

corresponding acceptance times efficiency, and  $\mathcal{B}$  is the branching fraction of the decay chain. For the  $pp$  cross section,  $\mathcal{L}$  represents the integrated luminosity. For the Pb-Pb cross section, the  $T_{AA}$  is the nuclear overlap function [39], equal to the number of  $NN$  binary collisions divided by the  $NN$  total inelastic cross section, and which can be interpreted as the  $NN$ -equivalent integrated luminosity per heavy ion collision.

The  $T_{AA}$  value for inclusive Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV is  $5.61 \text{ mb}^{-1}$ , as estimated from a Monte Carlo Glauber model [35,39].

Assuming that in the kinematic region accessible by the present measurement  $B^+$  and  $B^-$  production cross sections are equal, the factor  $1/2$  accounts for the fact that the yields are measured for particles and antiparticles added together, but the cross section is given for one species only.

The cross sections are affected by several sources of systematic uncertainties arising from the signal extraction, corrections,  $\mathcal{B}$ ,  $\mathcal{L}$ , or  $T_{AA}$  determination. The uncertainty of the modeling of the signal and background shapes (2.9% and 2.6% for  $pp$  and Pb-Pb cases, respectively) is evaluated on the  $p_T$  integrated bin, by varying the probability distribution functions used to describe the signal and background distributions. As an alternative combinatorial background shape, an exponential function and also second- and a third-order polynomials are used. The uncertainty of the signal modeling is evaluated by considering two fit variations: (i) leaving the width parameters free and (ii) using a sum of three Gaussian functions with common mean. The maximum of the signal variations is added in quadrature to the maximum of all the background variations, and propagated as the systematic uncertainty.

The systematic uncertainty due to the selection of the  $B$  meson candidates (3.8% for  $pp$  and 12.0% for Pb-Pb collisions) is estimated, in the  $p_T$  integrated bin, from several variations of the selection value for each of the following:  $\chi^2$  probability of the decay vertex, the 3D flight distance, the pointing angle, the track  $p_T$ , the track  $\eta$ , and the choice of the algorithm in the multivariate analysis.



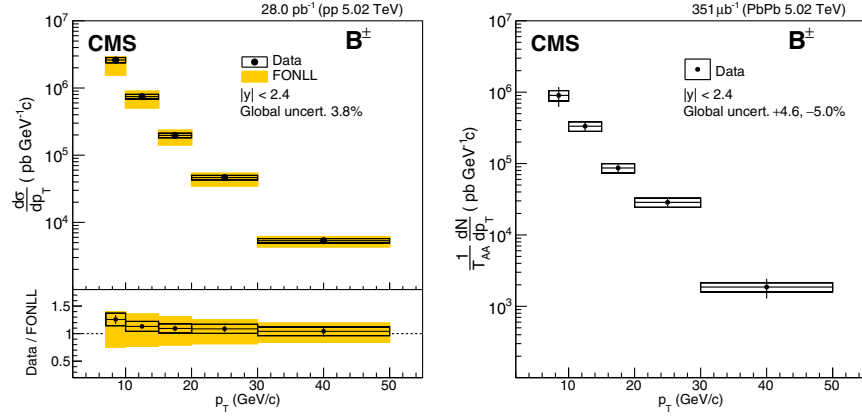


FIG. 2. The  $p_T$ -differential production cross section of  $B^\pm$  in  $pp$  (left) and Pb-Pb (right) collisions at  $\sqrt{s} = 5.02$  TeV. The vertical bars (boxes) correspond to statistical (systematic) uncertainties. The systematic uncertainty boxes here include both the correlated and uncorrelated contributions added in quadrature. The global systematic uncertainty is listed in the legend and not included in the point-to-point uncertainties. For the  $pp$  cross section, they comprise the uncertainties in the integrated luminosity measurement and in the branching fraction  $\mathcal{B}$ . For the Pb-Pb cross section, they comprise the uncertainties in  $T_{AA}$ ,  $N_{MB}$ , and  $\mathcal{B}$ . The  $pp$  cross section is compared to fixed-order plus next-to-leading logarithm (FONLL) calculations [41–43] represented by the colored boxes with the heights indicating the theoretical uncertainty.

In each case, a systematic uncertainty is estimated from all variations, as the maximum of 1 minus the ratio of the selection efficiencies (the ratio of the nominal yield and the yield after applying the modified selection) estimated in data and simulation. The total uncertainty for the selection of the  $B$  meson candidates is the quadratic sum of the individual contributions from the six settings.

The bin-by-bin systematic uncertainties associated with the acceptance correction (0.1–0.4%) are estimated by varying the shape of the generated  $B^\pm$  meson  $p_T$  and  $y$  spectra within limits defined by differences (including their statistical uncertainties) between data and MC calculations. Using these shape variations, “toy” MC simulations are used to recalculate the acceptance in each kinematic bin, the maximum variation between the nominal acceptance and the toys being propagated as the systematic uncertainty.

The uncertainty (2.8–5.5% in  $pp$  and 3.4–6.3% in Pb-Pb collisions) in the efficiency of the trigger, muon reconstruction, and muon identification is evaluated bin by bin using a data-driven technique [40]. Another systematic uncertainty is assigned for the track reconstruction efficiency (4% per track in  $pp$  collisions [26] and 6% in Pb-Pb collisions [35]). This uncertainty, together with all the others listed above as estimated on the  $p_T$  integrated bin, is considered as a correlated systematic uncertainty. The uncertainties calculated bin by bin are considered uncorrelated. The systematic uncertainty in the cross section measurement is computed as the sum in quadrature of the different contributions mentioned above. The uncertainty of the  $B^\pm$  meson decay  $\mathcal{B}$  is 3.1% [25]. The uncertainty of the number of minimum bias events in Pb-Pb,  $N_{MB}$ , is 1.0%. The  $T_{AA}$  uncertainty is +2.8%, –3.4% [35].

In Fig. 2, the  $p_T$ -differential production cross sections in  $pp$  and Pb-Pb collisions measured in the interval  $|y| < 2.4$

are presented. The  $pp$  result is compared to the cross section obtained from FONLL calculations [41]. The FONLL reference cross section is obtained by scaling the FONLL total  $b$ -quark production [41–43] by the world-average production fractions of  $B^+$  of 40.2% [25]. The calculated  $B^+$  FONLL reference is consistent with the measured  $B^\pm$   $pp$  spectrum, similarly to what was observed in the previous publications in  $pp$  collisions at  $\sqrt{s} = 7$  TeV [13–17].

The nuclear modification factor  $R_{AA}$ , shown in Fig. 3, is computed as

$$R_{AA}(p_T) = \frac{1}{T_{AA}} \frac{dN_{Pb-Pb}^{B^\pm}}{dp_T} \bigg/ \frac{d\sigma_{pp}^{B^\pm}}{dp_T}. \quad (3)$$

A clear suppression ( $R_{AA} < 1$ ) of  $B^\pm$  mesons production in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV is observed. The  $R_{AA}$  is around 0.3–0.6 for  $B^\pm$  mesons  $p_T$  from 7 to 50 GeV/ $c$ .

The  $p_T$  dependence of  $R_{AA}$  is compared to the predictions of (a) two perturbative QCD-based models that include both collisional and radiative energy loss (Djordjevic [46], CUJET3.0 [47–49]), (b) a transport theoretical model based on a Langevin equation that includes collisional energy loss and heavy quark diffusion in the medium (TAMU [44,45]), and (c) a model based on the anti-de Sitter/conformal field theory correspondence that includes thermal fluctuations in the energy loss for heavy quarks in a strongly coupled plasma (AdS/CFT HH [50,51]). The AdS/CFT HH calculation is provided for two settings of the diffusion coefficient  $D$  of the heavy-quark propagation through the medium: either dependent on or independent of the quark momentum. The four theoretical calculations differ in several aspects, e.g., the modeling of the Pb-Pb medium (hydrodynamically [45,47]

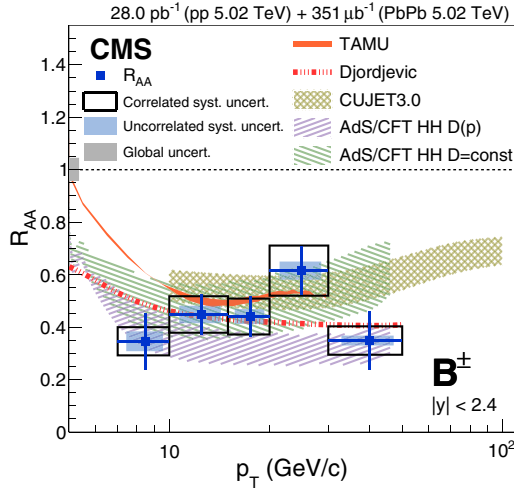


FIG. 3. The  $p_T$  dependence of the nuclear modification factor  $R_{AA}$  of  $B^\pm$  measured in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. The vertical bars (boxes) correspond to statistical (systematic) uncertainties. The global systematic uncertainty, represented as a grey box at  $R_{AA} = 1$ , comprises the uncertainties in the integrated luminosity measurement and  $T_{AA}$  value. Four theoretical calculations are also shown for comparison: TAMU [44,45], Djordjevic [46], CUJET3.0 [47–49], and anti-de Sitter/conformal field theory (AdS/CFT) HH [50,51]. The line width of the theoretical calculation from Ref. [44,45] represents the size of its statistical uncertainty.

or via a Glauber model [46]) and of the energy loss sources (partonic only [45,47] or also hadronic [45]), the set of the (nuclear) parton distribution functions used for the initial heavy-quark  $p_T$  distributions, etc. Given the current statistical and systematic uncertainties, all these theoretical predictions are roughly compatible with the measurement presented. However, while the present results cannot help to resolve the disagreements between different models because of the large uncertainties, including those of the theoretical calculations, they can already be used to optimize parameter settings in such models (e.g., the parton-medium coupling parameters in the AdS/CFT model). More precise measurements of the  $B^\pm$  mesons  $R_{AA}$  and future results on the angular correlations of  $B^\pm$  mesons with other hadrons will allow one to draw a firmer conclusion on the relevance of collisional and radiative processes in the  $b$  quark energy loss [52,53]. The measurement of exclusive  $B^\pm$  gives for the first time an unambiguous access to the  $b$  hadron quark-flavor content, and represents the first attempt to understand the interactions of beauty and light quarks with each other and with the medium they traverse before hadronization. This lays the groundwork for future measurements of azimuthal asymmetries or relative production ratios like  $B_s/B^\pm$  [54].

In summary, the first measurement of the differential production cross section of  $B^\pm$  mesons in  $pp$  and Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV has been presented. The  $B^\pm$  mesons are measured with the CMS detector at the LHC in the rapidity range  $|y| < 2.4$  and transverse momentum

interval  $7 < p_T < 50$  GeV/ $c$  via the reconstruction of one of their exclusive hadronic decay channels,  $B^\pm \rightarrow J/\psi K^\pm \rightarrow \mu^+ \mu^- K^\pm$ . The nuclear modification factor of  $B^\pm$  is measured as a function of its  $p_T$ . A strong suppression by about a factor of 2 is observed in the Pb-Pb system in comparison to expectations from the scaled  $pp$  reference data. The results are found to be roughly compatible with theoretical calculations incorporating beauty quark diffusion and energy loss in a quark-gluon plasma.

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT, and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and RAEP (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER Fondo Europeo de Desarrollo Regional, Spain (Spain); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

- 
- [1] É. V. Shuryak, Theory of hadronic plasma, *Sov. Phys. JETP* **47**, 212 (1978).
  - [2] J. C. Collins and M. J. Perry, Superdense Matter: Neutrons or Asymptotically Free Quarks?, *Phys. Rev. Lett.* **34**, 1353 (1975).
  - [3] F. Karsch and E. Laermann, in *Quark-Gluon Plasma III*, edited by R. Hwa (World Scientific Publishing, Hackensack, 2004).
  - [4] J. D. Bjorken, Fermilab Report No. PUB 82-059-THY, 1982, <http://lss.fnal.gov/archive/1982/pub/Pub-82-059-T.pdf>.

- [5] R. Baier, D. Schiff, and B. G. Zakharov, Energy loss in perturbative QCD, *Annu. Rev. Nucl. Part. Sci.* **50**, 37 (2000).
- [6] CMS Collaboration, Observation and studies of jet quenching in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, *Phys. Rev. C* **84**, 024906 (2011).
- [7] ATLAS Collaboration, Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at  $\sqrt{s_{NN}} = 2.76$  TeV with the ATLAS Detector at the LHC, *Phys. Rev. Lett.* **105**, 252303 (2010).
- [8] Y. L. Dokshitzer and D. E. Kharzeev, Heavy quark colorimetry of QCD matter, *Phys. Lett. B* **519**, 199 (2001).
- [9] N. Armesto, C. A. Salgado, and U. A. Wiedemann, Medium-induced gluon radiation off massive quarks fills the dead cone, *Phys. Rev. D* **69**, 114003 (2004).
- [10] S. Wicks, W. Horowitz, M. Djordjevic, and M. Gyulassy, Heavy quark jet quenching with collisional plus radiative energy loss and path length fluctuations, *Nucl. Phys. A* **783**, 493 (2007).
- [11] B.-W. Zhang, E. Wang, and X.-N. Wang, Heavy Quark Energy Loss in Nuclear Medium, *Phys. Rev. Lett.* **93**, 072301 (2004).
- [12] A. Adil and I. Vitev, Collisional dissociation of heavy mesons in dense QCD matter, *Phys. Lett. B* **649**, 139 (2007).
- [13] CMS Collaboration, Measurement of the  $B^+$  Production Cross Section in  $pp$  Collisions at  $\sqrt{s} = 7$  TeV, *Phys. Rev. Lett.* **106**, 112001 (2011).
- [14] CMS Collaboration, Measurement of the  $B^0$  Production Cross Section in  $pp$  Collisions at  $\sqrt{s} = 7$  TeV, *Phys. Rev. Lett.* **106**, 252001 (2011).
- [15] CMS Collaboration, Measurement of the  $B_s^0$  production cross section with  $B_s^0 \rightarrow J/\psi\phi$  decays in  $pp$  collisions at  $\sqrt{s} = 7$  TeV, *Phys. Rev. D* **84**, 052008 (2011).
- [16] ATLAS Collaboration, Measurement of the differential cross section of  $B^+$  meson production in pp collisions at  $\sqrt{s} = 7$  TeV at ATLAS, *J. High Energy Phys.* **10** (2013) 042.
- [17] LHCb Collaboration, Measurement of  $B$  meson production cross sections in proton-proton collisions at  $\sqrt{s} = 7$  TeV, *J. High Energy Phys.* **08** (2013) 117.
- [18] LHCb Collaboration, Measurement of the  $\chi_{b1}(3P)$  mass and of the relative rate of  $\chi_{b1}(1P)$  and  $\chi_{b2}(1P)$  production, *J. High Energy Phys.* **10** (2014) 88.
- [19] LHCb Collaboration, Measurements of  $B_c^+$  Production and Mass with the  $B_c^+ \rightarrow J/\psi\pi^+$  Decay, *Phys. Rev. Lett.* **109**, 232001 (2012).
- [20] LHCb Collaboration, Study of the production of  $\Lambda_b^0$  and  $\bar{b}^0$  hadrons in pp collisions and first measurement of the  $\Lambda_b^0 \rightarrow J/\psi p K^-$  branching fraction, *Chin. Phys. C* **40**, 011001 (2016).
- [21] LHCb Collaboration, Measurement of  $B_c^+$  Production in Proton-Proton Collisions at  $\sqrt{s} = 8$  TeV, *Phys. Rev. Lett.* **114**, 132001 (2015).
- [22] CMS Collaboration, Measurement of the total and differential inclusive  $B^+$  hadron cross sections in pp collisions at  $\sqrt{s} = 13$  TeV, *Phys. Lett. B* **771**, 435 (2017).
- [23] CMS Collaboration, Study of  $B$  Meson Production in  $p + \text{Pb}$  Collisions at  $\sqrt{s_{NN}} = 5.02$  TeV using Exclusive Hadronic Decays, *Phys. Rev. Lett.* **116**, 032301 (2016).
- [24] CMS Collaboration, Suppression of nonprompt  $J/\psi$ , prompt  $J/\psi$ , and  $\Upsilon(1S)$  in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, *J. High Energy Phys.* **05** (2012) 063.
- [25] C. Patrignani *et al.* (Particle Data Group), Review of particle physics, *Chin. Phys. C* **40**, 100001 (2016).
- [26] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [27] CMS Collaboration, Performance of CMS muon reconstruction in  $pp$  collision events at  $\sqrt{s} = 7$  TeV, *J. Instrum.* **7**, P10002 (2012).
- [28] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [29] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [30] CMS Collaboration, Event generator tunes obtained from underlying event and multiparton scattering measurements, *Eur. Phys. J. C* **76**, 155 (2016).
- [31] S. Agostinelli *et al.* (GEANT4), GEANT4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [32] D. J. Lange, The EvtGen particle decay simulation package, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [33] E. Barberio, B. van Eijk, and Z. Was, Photos—a universal Monte Carlo for QED radiative corrections in decays, *Comput. Phys. Commun.* **66**, 115 (1991).
- [34] I. P. Lokhtin and A. M. Snigirev, A model of jet quenching in ultrarelativistic heavy ion collisions and high- $p_T$  hadron spectra at RHIC, *Eur. Phys. J. C* **45**, 211 (2006).
- [35] CMS Collaboration, Charged-particle nuclear modification factors in Pb-Pb and pPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *J. High Energy Phys.* **04** (2017) 039.
- [36] CMS Collaboration, Transverse momentum and pseudorapidity distributions of charged hadrons in  $pp$  collisions at  $\sqrt{s} = 0.9$  and 2.76 TeV, *J. High Energy Phys.* **02** (2010) 041.
- [37] CMS Collaboration, CMS Report No. CMS-PAS-LUM-16-001, 2016, <https://cds.cern.ch/record/2235781>.
- [38] H. Voss, A. Höcker, J. Stelzer, and F. Tegenfeldt, in *XIth International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT)* (PoS Editorial Office, Trieste, 2007), p. 40.
- [39] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Glauber modeling in high-energy nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* **57**, 205 (2007).
- [40] CMS Collaboration, Measurements of inclusive  $W$  and  $Z$  cross sections in  $pp$  collisions at  $\sqrt{s} = 7$  TeV, *J. High Energy Phys.* **01** (2011) 080.
- [41] M. Cacciari, S. Frixione, N. Houdeau, M. L. Mangano, P. Nason, and G. Ridolfi, Theoretical predictions for charm and bottom production at the LHC, *J. High Energy Phys.* **10** (2012) 137.
- [42] M. Cacciari, M. Greco, and P. Nason, The  $p_T$  spectrum in heavy-flavor hadroproduction, *J. High Energy Phys.* **05** (1998) 007.
- [43] M. Cacciari and P. Nason, Charm cross sections for the Tevatron Run II, *J. High Energy Phys.* **09** (2003) 006.



- [44] M. He, R. J. Fries, and R. Rapp, Heavy-quark diffusion and hadronization in quark-gluon plasma, *Phys. Rev. C* **86**, 014903 (2012).
- [45] M. He, R. J. Fries, and R. Rapp, Heavy flavor at the Large Hadron Collider in a strong coupling approach, *Phys. Lett. B* **735**, 445 (2014).
- [46] M. Djordjevic, B. Blagojevic, and L. Zivkovic, Mass tomography at different momentum ranges in quark-gluon plasma, *Phys. Rev. C* **94**, 044908 (2016).
- [47] J. Xu, J. Liao, and M. Gyulassy, Bridging soft-hard transport properties of quark-gluon plasmas with CUJET3.0, *J. High Energy Phys.* **02** (2016) 169.
- [48] J. Xu, J. Liao, and M. Gyulassy, Consistency of perfect fluidity and jet quenching in semiquark-gluon monopole plasmas, *Chin. Phys. Lett.* **32**, 092501 (2015).
- [49] J. Xu, A. Buzzatti, and M. Gyulassy, Azimuthal jet flavor tomography with CUJET2.0 of nuclear collisions at RHIC and LHC, *J. High Energy Phys.* **08** (2014) 063.
- [50] W. A. Horowitz, Fluctuating heavy quark energy loss in a strongly coupled quark-gluon plasma, *Phys. Rev. D* **91**, 085019 (2015).
- [51] R. Hambrock and W. A. Horowitz, AdS/CFT predictions for azimuthal and momentum correlations of  $b\bar{b}$  pairs in heavy ion collisions, [arXiv:1703.05845](https://arxiv.org/abs/1703.05845).
- [52] M. Rohrmoser, P. B. Gossiaux, T. Gousset, and J. Aichelin, Proceedings, 16th international conference on strangeness in quark matter (SQM 2016), Berkeley, California, United States *J. Phys. Conf. Ser.* **779**, 012032 (2017).
- [53] S. Cao, G.-Y. Qin, and S. A. Bass, in XXIV international conference on ultrarelativistic nucleus-nucleus collisions, *Nucl. Phys.* **A931**, 569 (2014).
- [54] M. He, R. J. Fries, and R. Rapp,  $D_s$  Meson as Quantitative Probe of Diffusion and Hadronization in Nuclear Collisions, *Phys. Rev. Lett.* **110**, 112301 (2013).

---

A. M. Sirunyan,<sup>1</sup> A. Tumasyan,<sup>1</sup> W. Adam,<sup>2</sup> E. Asilar,<sup>2</sup> T. Bergauer,<sup>2</sup> J. Brandstetter,<sup>2</sup> E. Brondolin,<sup>2</sup> M. Dragicevic,<sup>2</sup> J. Erö,<sup>2</sup> M. Flechl,<sup>2</sup> M. Friedl,<sup>2</sup> R. Frühwirth,<sup>2,a</sup> V. M. Ghete,<sup>2</sup> N. Hörmann,<sup>2</sup> J. Hrubec,<sup>2</sup> M. Jeitler,<sup>2,a</sup> A. König,<sup>2</sup> I. Krätschmer,<sup>2</sup> D. Liko,<sup>2</sup> T. Matsushita,<sup>2</sup> I. Mikulec,<sup>2</sup> D. Rabady,<sup>2</sup> N. Rad,<sup>2</sup> H. Rohringer,<sup>2</sup> J. Schieck,<sup>2,a</sup> J. Strauss,<sup>2</sup> W. Waltenberger,<sup>2</sup> C.-E. Wulz,<sup>2,a</sup> V. Chekhovsky,<sup>3</sup> V. Mossolov,<sup>3</sup> J. Suarez Gonzalez,<sup>3</sup> N. Shumeiko,<sup>4</sup> S. Alderweireldt,<sup>5</sup> E. A. De Wolf,<sup>5</sup> X. Janssen,<sup>5</sup> J. Lauwers,<sup>5</sup> M. Van De Klundert,<sup>5</sup> H. Van Haevermaet,<sup>5</sup> P. Van Mechelen,<sup>5</sup> N. Van Remortel,<sup>5</sup> A. Van Spilbeeck,<sup>5</sup> S. Abu Zeid,<sup>6</sup> F. Blekman,<sup>6</sup> J. D'Hondt,<sup>6</sup> I. De Bruyn,<sup>6</sup> J. De Clercq,<sup>6</sup> K. Deroover,<sup>6</sup> S. Lowette,<sup>6</sup> S. Moortgat,<sup>6</sup> L. Moreels,<sup>6</sup> A. Olbrechts,<sup>6</sup> Q. Python,<sup>6</sup> K. Skovpen,<sup>6</sup> S. Tavernier,<sup>6</sup> W. Van Doninck,<sup>6</sup> P. Van Mulders,<sup>6</sup> I. Van Parijs,<sup>6</sup> H. Brun,<sup>7</sup> B. Clerbaux,<sup>7</sup> G. De Lentdecker,<sup>7</sup> H. Delannoy,<sup>7</sup> G. Fasanella,<sup>7</sup> L. Favart,<sup>7</sup> R. Goldouzian,<sup>7</sup> A. Grebenyuk,<sup>7</sup> G. Karapostoli,<sup>7</sup> T. Lenzi,<sup>7</sup> J. Luetic,<sup>7</sup> T. Maerschalk,<sup>7</sup> A. Marinov,<sup>7</sup> A. Randle-conde,<sup>7</sup> T. Seva,<sup>7</sup> C. Vander Velde,<sup>7</sup> P. Vanlaer,<sup>7</sup> D. Vannerom,<sup>7</sup> R. Yonamine,<sup>7</sup> F. Zenoni,<sup>7</sup> F. Zhang,<sup>7,b</sup> A. Cimmino,<sup>8</sup> T. Cornelis,<sup>8</sup> D. Dobur,<sup>8</sup> A. Fagot,<sup>8</sup> M. Gul,<sup>8</sup> I. Khvastunov,<sup>8</sup> D. Poyraz,<sup>8</sup> S. Salva,<sup>8</sup> R. Schöfbeck,<sup>8</sup> M. Tytgat,<sup>8</sup> W. Van Driessche,<sup>8</sup> W. Verbeke,<sup>8</sup> N. Zaganidis,<sup>8</sup> H. Bakhshiansohi,<sup>9</sup> O. Bondu,<sup>9</sup> S. Brochet,<sup>9</sup> G. Bruno,<sup>9</sup> A. Caudron,<sup>9</sup> S. De Visscher,<sup>9</sup> C. Delaere,<sup>9</sup> M. Delcourt,<sup>9</sup> B. Francois,<sup>9</sup> A. Giammanco,<sup>9</sup> A. Jafari,<sup>9</sup> M. Komm,<sup>9</sup> G. Krintiras,<sup>9</sup> V. Lemaître,<sup>9</sup> A. Magitteri,<sup>9</sup> A. Mertens,<sup>9</sup> M. Musich,<sup>9</sup> K. Piotrkowski,<sup>9</sup> L. Quertenmont,<sup>9</sup> M. Vidal Marono,<sup>9</sup> S. Wertz,<sup>9</sup> N. Beliy,<sup>10</sup> W. L. Aldá Júnior,<sup>11</sup> F. L. Alves,<sup>11</sup> G. A. Alves,<sup>11</sup> L. Brito,<sup>11</sup> C. Hensel,<sup>11</sup> A. Moraes,<sup>11</sup> M. E. Pol,<sup>11</sup> P. Rebello Teles,<sup>11</sup> E. Belchior Batista Das Chagas,<sup>12</sup> W. Carvalho,<sup>12</sup> J. Chinellato,<sup>12,c</sup> A. Custódio,<sup>12</sup> E. M. Da Costa,<sup>12</sup> G. G. Da Silveira,<sup>12,d</sup> D. De Jesus Damiao,<sup>12</sup> S. Fonseca De Souza,<sup>12</sup> L. M. Huertas Guativa,<sup>12</sup> H. Malbouisson,<sup>12</sup> C. Mora Herrera,<sup>12</sup> L. Mundim,<sup>12</sup> H. Nogima,<sup>12</sup> A. Santoro,<sup>12</sup> A. Sznajder,<sup>12</sup> E. J. Tonelli Manganote,<sup>12,c</sup> F. Torres Da Silva De Araujo,<sup>12</sup> A. Vilela Pereira,<sup>12</sup> S. Ahuja,<sup>13a</sup> C. A. Bernardes,<sup>13a</sup> T. R. Fernandez Perez Tomei,<sup>13a</sup> E. M. Gregores,<sup>13b</sup> P. G. Mercadante,<sup>13b</sup> C. S. Moon,<sup>13a</sup> S. F. Novaes,<sup>13a</sup> Sandra S. Padula,<sup>13a</sup> D. Romero Abad,<sup>13b</sup> J. C. Ruiz Vargas,<sup>13a</sup> A. Aleksandrov,<sup>14</sup> R. Hadjiiska,<sup>14</sup> P. Iaydjiev,<sup>14</sup> M. Rodozov,<sup>14</sup> S. Stoykova,<sup>14</sup> G. Sultanov,<sup>14</sup> M. Vutova,<sup>14</sup> A. Dimitrov,<sup>15</sup> I. Glushkov,<sup>15</sup> L. Litov,<sup>15</sup> B. Pavlov,<sup>15</sup> P. Petkov,<sup>15</sup> W. Fang,<sup>16,e</sup> X. Gao,<sup>16,e</sup> M. Ahmad,<sup>17</sup> J. G. Bian,<sup>17</sup> G. M. Chen,<sup>17</sup> H. S. Chen,<sup>17</sup> M. Chen,<sup>17</sup> Y. Chen,<sup>17</sup> C. H. Jiang,<sup>17</sup> D. Leggat,<sup>17</sup> Z. Liu,<sup>17</sup> F. Romeo,<sup>17</sup> S. M. Shaheen,<sup>17</sup> A. Spiezia,<sup>17</sup> J. Tao,<sup>17</sup> C. Wang,<sup>17</sup> Z. Wang,<sup>17</sup> E. Yazgan,<sup>17</sup> H. Zhang,<sup>17</sup> J. Zhao,<sup>17</sup> Y. Ban,<sup>18</sup> G. Chen,<sup>18</sup> Q. Li,<sup>18</sup> S. Liu,<sup>18</sup> Y. Mao,<sup>18</sup> S. J. Qian,<sup>18</sup> D. Wang,<sup>18</sup> Z. Xu,<sup>18</sup> C. Avila,<sup>19</sup> A. Cabrera,<sup>19</sup> L. F. Chaparro Sierra,<sup>19</sup> C. Florez,<sup>19</sup> C. F. González Hernández,<sup>19</sup> J. D. Ruiz Alvarez,<sup>19</sup> N. Godinovic,<sup>20</sup> D. Lelas,<sup>20</sup> I. Puljak,<sup>20</sup> P. M. Ribeiro Cipriano,<sup>20</sup> T. Sculac,<sup>20</sup> Z. Antunovic,<sup>21</sup> M. Kovac,<sup>21</sup> V. Brigljevic,<sup>22</sup> D. Ferencek,<sup>22</sup> K. Kadija,<sup>22</sup> B. Mesic,<sup>22</sup> T. Susa,<sup>22</sup> M. W. Ather,<sup>23</sup> A. Attikis,<sup>23</sup> G. Mavromanolakis,<sup>23</sup> J. Mousa,<sup>23</sup> C. Nicolaou,<sup>23</sup> F. Ptochos,<sup>23</sup> P. A. Razis,<sup>23</sup> H. Rykaczewski,<sup>23</sup> M. Finger,<sup>24,f</sup> M. Finger Jr.,<sup>24,f</sup> E. Carrera Jarrin,<sup>25</sup> Y. Assran,<sup>26,g,h</sup> M. A. Mahmoud,<sup>26,i,h</sup> A. Mahrous,<sup>26,j</sup> R. K. Dewanjee,<sup>27</sup> M. Kadastik,<sup>27</sup> L. Perrini,<sup>27</sup> M. Raidal,<sup>27</sup> A. Tiko,<sup>27</sup> C. Veelken,<sup>27</sup> P. Eerola,<sup>28</sup> J. Pekkanen,<sup>28</sup> M. Voutilainen,<sup>28</sup> J. Härkönen,<sup>29</sup> T. Järvinen,<sup>29</sup> V. Karimäki,<sup>29</sup> R. Kinnunen,<sup>29</sup> T. Lampén,<sup>29</sup> K. Lassila-Perini,<sup>29</sup> S. Lehti,<sup>29</sup> T. Lindén,<sup>29</sup> P. Luukka,<sup>29</sup> E. Tuominen,<sup>29</sup> J. Tuominiemi,<sup>29</sup> E. Tuovinen,<sup>29</sup>



J. Talvitie,<sup>30</sup> T. Tuuva,<sup>30</sup> M. Besancon,<sup>31</sup> F. Couderc,<sup>31</sup> M. Dejjardin,<sup>31</sup> D. Denegri,<sup>31</sup> J. L. Faure,<sup>31</sup> F. Ferri,<sup>31</sup> S. Ganjour,<sup>31</sup> S. Ghosh,<sup>31</sup> A. Givernaud,<sup>31</sup> P. Gras,<sup>31</sup> G. Hamel de Monchenault,<sup>31</sup> P. Jarry,<sup>31</sup> I. Kucher,<sup>31</sup> E. Locci,<sup>31</sup> M. Machet,<sup>31</sup> J. Malcles,<sup>31</sup> J. Rander,<sup>31</sup> A. Rosowsky,<sup>31</sup> M. Ö. Sahin,<sup>31</sup> M. Titov,<sup>31</sup> A. Abdulsalam,<sup>32</sup> I. Antropov,<sup>32</sup> S. Baffioni,<sup>32</sup> F. Beaudette,<sup>32</sup> P. Busson,<sup>32</sup> L. Cadamuro,<sup>32</sup> E. Chapon,<sup>32</sup> C. Charlotte,<sup>32</sup> O. Davignon,<sup>32</sup> R. Granier de Cassagnac,<sup>32</sup> M. Jo,<sup>32</sup> S. Lisniak,<sup>32</sup> A. Lobanov,<sup>32</sup> P. Miné,<sup>32</sup> M. Nguyen,<sup>32</sup> C. Ochando,<sup>32</sup> G. Ortona,<sup>32</sup> P. Paganini,<sup>32</sup> P. Pigard,<sup>32</sup> S. Regnard,<sup>32</sup> R. Salerno,<sup>32</sup> Y. Sirois,<sup>32</sup> A. G. Stahl Leiton,<sup>32</sup> T. Strebler,<sup>32</sup> Y. Yilmaz,<sup>32</sup> A. Zabi,<sup>32</sup> J.-L. Agram,<sup>33,k</sup> J. Andrea,<sup>33</sup> D. Bloch,<sup>33</sup> J.-M. Brom,<sup>33</sup> M. Buttignol,<sup>33</sup> E. C. Chabert,<sup>33</sup> N. Chanon,<sup>33</sup> C. Collard,<sup>33</sup> E. Conte,<sup>33,k</sup> X. Coubez,<sup>33</sup> J.-C. Fontaine,<sup>33,k</sup> D. Gelé,<sup>33</sup> U. Goerlach,<sup>33</sup> A.-C. Le Bihan,<sup>33</sup> P. Van Hove,<sup>33</sup> S. Gadrat,<sup>34</sup> S. Beauceron,<sup>35</sup> C. Bernet,<sup>35</sup> G. Boudoul,<sup>35</sup> R. Chierici,<sup>35</sup> D. Contardo,<sup>35</sup> B. Courbon,<sup>35</sup> P. Depasse,<sup>35</sup> H. El Mamouni,<sup>35</sup> J. Fay,<sup>35</sup> L. Finco,<sup>35</sup> S. Gascon,<sup>35</sup> M. Gouzevitch,<sup>35</sup> G. Grenier,<sup>35</sup> B. Ille,<sup>35</sup> F. Lagarde,<sup>35</sup> I. B. Laktineh,<sup>35</sup> M. Lethuillier,<sup>35</sup> L. Mirabito,<sup>35</sup> A. L. Pequegnot,<sup>35</sup> S. Perries,<sup>35</sup> A. Popov,<sup>35,l</sup> V. Sordini,<sup>35</sup> M. Vander Donckt,<sup>35</sup> S. Viret,<sup>35</sup> A. Khvedelidze,<sup>36,f</sup> Z. Tsamalaidze,<sup>37,f</sup> C. Autermann,<sup>38</sup> S. Beranek,<sup>38</sup> L. Feld,<sup>38</sup> M. K. Kiesel,<sup>38</sup> K. Klein,<sup>38</sup> M. Lipinski,<sup>38</sup> M. Preuten,<sup>38</sup> C. Schomakers,<sup>38</sup> J. Schulz,<sup>38</sup> T. Verlage,<sup>38</sup> A. Albert,<sup>39</sup> M. Brodski,<sup>39</sup> E. Dietz-Laursonn,<sup>39</sup> D. Duchardt,<sup>39</sup> M. Endres,<sup>39</sup> M. Erdmann,<sup>39</sup> S. Erdweg,<sup>39</sup> T. Esch,<sup>39</sup> R. Fischer,<sup>39</sup> A. Güth,<sup>39</sup> M. Hamer,<sup>39</sup> T. Hebbeker,<sup>39</sup> C. Heidemann,<sup>39</sup> K. Hoepfner,<sup>39</sup> S. Knutzen,<sup>39</sup> M. Merschmeyer,<sup>39</sup> A. Meyer,<sup>39</sup> P. Millet,<sup>39</sup> S. Mukherjee,<sup>39</sup> M. Olschewski,<sup>39</sup> K. Padeken,<sup>39</sup> T. Pook,<sup>39</sup> M. Radziej,<sup>39</sup> H. Reithler,<sup>39</sup> M. Rieger,<sup>39</sup> F. Scheuch,<sup>39</sup> L. Sonnenschein,<sup>39</sup> D. Teyssier,<sup>39</sup> S. Thüer,<sup>39</sup> G. Flügge,<sup>40</sup> B. Kargoll,<sup>40</sup> T. Kress,<sup>40</sup> A. Künsken,<sup>40</sup> J. Lingemann,<sup>40</sup> T. Müller,<sup>40</sup> A. Nehrkorn,<sup>40</sup> A. Nowack,<sup>40</sup> C. Pistone,<sup>40</sup> O. Pooth,<sup>40</sup> A. Stahl,<sup>40,m</sup> M. Aldaya Martin,<sup>41</sup> T. Arndt,<sup>41</sup> C. Asawatangtrakuldee,<sup>41</sup> K. Beernaert,<sup>41</sup> O. Behnke,<sup>41</sup> U. Behrens,<sup>41</sup> A. A. Bin Anuar,<sup>41</sup> K. Borras,<sup>41,n</sup> V. Botta,<sup>41</sup> A. Campbell,<sup>41</sup> P. Connor,<sup>41</sup> C. Contreras-Campana,<sup>41</sup> F. Costanza,<sup>41</sup> C. Diez Pardos,<sup>41</sup> G. Eckerlin,<sup>41</sup> D. Eckstein,<sup>41</sup> T. Eichhorn,<sup>41</sup> E. Eren,<sup>41</sup> E. Gallo,<sup>41,o</sup> J. Garay Garcia,<sup>41</sup> A. Geiser,<sup>41</sup> A. Gizhko,<sup>41</sup> J. M. Grados Luyando,<sup>41</sup> A. Grohsjean,<sup>41</sup> P. Gunnellini,<sup>41</sup> A. Harb,<sup>41</sup> J. Hauk,<sup>41</sup> M. Hempel,<sup>41,p</sup> H. Jung,<sup>41</sup> A. Kalogeropoulos,<sup>41</sup> M. Kasemann,<sup>41</sup> J. Keaveney,<sup>41</sup> C. Kleinwort,<sup>41</sup> I. Korol,<sup>41</sup> D. Krücker,<sup>41</sup> W. Lange,<sup>41</sup> A. Lelek,<sup>41</sup> T. Lenz,<sup>41</sup> J. Leonard,<sup>41</sup> K. Lipka,<sup>41</sup> W. Lohmann,<sup>41,p</sup> R. Mankel,<sup>41</sup> I.-A. Melzer-Pellmann,<sup>41</sup> A. B. Meyer,<sup>41</sup> G. Mittag,<sup>41</sup> J. Mnich,<sup>41</sup> A. Mussgiller,<sup>41</sup> E. Ntomari,<sup>41</sup> D. Pitzl,<sup>41</sup> R. Placakyte,<sup>41</sup> A. Raspereza,<sup>41</sup> B. Roland,<sup>41</sup> M. Savitskyi,<sup>41</sup> P. Saxena,<sup>41</sup> R. Shevchenko,<sup>41</sup> S. Spannagel,<sup>41</sup> N. Stefaniuk,<sup>41</sup> G. P. Van Onsem,<sup>41</sup> R. Walsh,<sup>41</sup> Y. Wen,<sup>41</sup> K. Wichmann,<sup>41</sup> C. Wissing,<sup>41</sup> S. Bein,<sup>42</sup> V. Blobel,<sup>42</sup> M. Centis Vignali,<sup>42</sup> A. R. Draeger,<sup>42</sup> T. Dreyer,<sup>42</sup> E. Garutti,<sup>42</sup> D. Gonzalez,<sup>42</sup> J. Haller,<sup>42</sup> M. Hoffmann,<sup>42</sup> A. Junkes,<sup>42</sup> R. Klanner,<sup>42</sup> R. Kogler,<sup>42</sup> N. Kovalchuk,<sup>42</sup> S. Kurz,<sup>42</sup> T. Lapsien,<sup>42</sup> I. Marchesini,<sup>42</sup> D. Marconi,<sup>42</sup> M. Meyer,<sup>42</sup> M. Niedziela,<sup>42</sup> D. Nowatschin,<sup>42</sup> F. Pantaleo,<sup>42,m</sup> T. Peiffer,<sup>42</sup> A. Perieanu,<sup>42</sup> C. Scharf,<sup>42</sup> P. Schleper,<sup>42</sup> A. Schmidt,<sup>42</sup> S. Schumann,<sup>42</sup> J. Schwandt,<sup>42</sup> J. Sonneveld,<sup>42</sup> H. Stadie,<sup>42</sup> G. Steinbrück,<sup>42</sup> F. M. Stober,<sup>42</sup> M. Stöver,<sup>42</sup> H. Tholen,<sup>42</sup> D. Troendle,<sup>42</sup> E. Usai,<sup>42</sup> L. Vanelderen,<sup>42</sup> A. Vanhoefer,<sup>42</sup> B. Vormwald,<sup>42</sup> M. Akbiyik,<sup>43</sup> C. Barth,<sup>43</sup> S. Baur,<sup>43</sup> C. Baus,<sup>43</sup> J. Berger,<sup>43</sup> E. Butz,<sup>43</sup> R. Caspart,<sup>43</sup> T. Chwalek,<sup>43</sup> F. Colombo,<sup>43</sup> W. De Boer,<sup>43</sup> A. Dierlamm,<sup>43</sup> B. Freund,<sup>43</sup> R. Friese,<sup>43</sup> M. Giffels,<sup>43</sup> A. Gilbert,<sup>43</sup> D. Haitz,<sup>43</sup> F. Hartmann,<sup>43,m</sup> S. M. Heindl,<sup>43</sup> U. Husemann,<sup>43</sup> F. Kassel,<sup>43,m</sup> S. Kudella,<sup>43</sup> H. Mildner,<sup>43</sup> M. U. Mozer,<sup>43</sup> Th. Müller,<sup>43</sup> M. Plagge,<sup>43</sup> G. Quast,<sup>43</sup> K. Rabbertz,<sup>43</sup> M. Schröder,<sup>43</sup> I. Shvetsov,<sup>43</sup> G. Sieber,<sup>43</sup> H. J. Simonis,<sup>43</sup> R. Ulrich,<sup>43</sup> S. Wayand,<sup>43</sup> M. Weber,<sup>43</sup> T. Weiler,<sup>43</sup> S. Williamson,<sup>43</sup> C. Wöhrmann,<sup>43</sup> R. Wolf,<sup>43</sup> G. Anagnostou,<sup>44</sup> G. Daskalakis,<sup>44</sup> T. Geralis,<sup>44</sup> V. A. Giakoumopoulou,<sup>44</sup> A. Kyriakis,<sup>44</sup> D. Loukas,<sup>44</sup> I. Topsis-Giotis,<sup>44</sup> S. Kesisoglou,<sup>45</sup> A. Panagiotou,<sup>45</sup> N. Saoulidou,<sup>45</sup> I. Evangelou,<sup>46</sup> G. Flouris,<sup>46</sup> C. Foudas,<sup>46</sup> P. Kokkas,<sup>46</sup> N. Manthos,<sup>46</sup> I. Papadopoulos,<sup>46</sup> E. Paradas,<sup>46</sup> J. Strologas,<sup>46</sup> F. A. Triantis,<sup>46</sup> M. Csanad,<sup>47</sup> N. Filipovic,<sup>47</sup> G. Pasztor,<sup>47</sup> G. Bencze,<sup>48</sup> C. Hajdu,<sup>48</sup> D. Horvath,<sup>48,q</sup> F. Sikler,<sup>48</sup> V. Veszpremi,<sup>48</sup> G. Vesztergombi,<sup>48,r</sup> A. J. Zsigmond,<sup>48</sup> N. Beni,<sup>49</sup> S. Czellar,<sup>49</sup> J. Karancsi,<sup>49,s</sup> A. Makovec,<sup>49</sup> J. Molnar,<sup>49</sup> Z. Szillasi,<sup>49</sup> M. Bartók,<sup>50,r</sup> P. Raics,<sup>50</sup> Z. L. Trocsanyi,<sup>50</sup> B. Ujvari,<sup>50</sup> S. Choudhury,<sup>51</sup> J. R. Komaragiri,<sup>51</sup> S. Bahinipati,<sup>52,t</sup> S. Bhowmik,<sup>52</sup> P. Mal,<sup>52</sup> K. Mandal,<sup>52</sup> A. Nayak,<sup>52,u</sup> D. K. Sahoo,<sup>52,t</sup> N. Sahoo,<sup>52</sup> S. K. Swain,<sup>52</sup> S. Bansal,<sup>53</sup> S. B. Beri,<sup>53</sup> V. Bhatnagar,<sup>53</sup> R. Chawla,<sup>53</sup> N. Dhingra,<sup>53</sup> U. Bhawandeep,<sup>53</sup> A. K. Kalsi,<sup>53</sup> A. Kaur,<sup>53</sup> M. Kaur,<sup>53</sup> R. Kumar,<sup>53</sup> P. Kumari,<sup>53</sup> A. Mehta,<sup>53</sup> M. Mittal,<sup>53</sup> J. B. Singh,<sup>53</sup> G. Walia,<sup>53</sup> Ashok Kumar,<sup>54</sup> Aashaq Shah,<sup>54</sup> A. Bhardwaj,<sup>54</sup> S. Chauhan,<sup>54</sup> B. C. Choudhary,<sup>54</sup> R. B. Garg,<sup>54</sup> S. Keshri,<sup>54</sup> S. Malhotra,<sup>54</sup> M. Naimuddin,<sup>54</sup> K. Ranjan,<sup>54</sup> R. Sharma,<sup>54</sup> V. Sharma,<sup>54</sup> R. Bhardwaj,<sup>55</sup> R. Bhattacharya,<sup>55</sup> S. Bhattacharya,<sup>55</sup> S. Dey,<sup>55</sup> S. Dutt,<sup>55</sup> S. Dutta,<sup>55</sup> S. Ghosh,<sup>55</sup> N. Majumdar,<sup>55</sup> A. Modak,<sup>55</sup> K. Mondal,<sup>55</sup> S. Mukhopadhyay,<sup>55</sup> S. Nandan,<sup>55</sup> A. Purohit,<sup>55</sup> A. Roy,<sup>55</sup> D. Roy,<sup>55</sup> S. Roy Chowdhury,<sup>55</sup> S. Sarkar,<sup>55</sup> M. Sharan,<sup>55</sup> S. Thakur,<sup>55</sup> P. K. Behera,<sup>56</sup> R. Chudasama,<sup>57</sup> D. Dutta,<sup>57</sup> V. Jha,<sup>57</sup> V. Kumar,<sup>57</sup> A. K. Mohanty,<sup>57,m</sup> P. K. Netrakanti,<sup>57</sup> L. M. Pant,<sup>57</sup> P. Shukla,<sup>57</sup> A. Topkar,<sup>57</sup> T. Aziz,<sup>58</sup> S. Dugad,<sup>58</sup> B. Mahakud,<sup>58</sup> S. Mitra,<sup>58</sup> G. B. Mohanty,<sup>58</sup> B. Parida,<sup>58</sup> N. Sur,<sup>58</sup> B. Sutar,<sup>58</sup> S. Banerjee,<sup>59</sup> S. Bhattacharya,<sup>59</sup> S. Chatterjee,<sup>59</sup> P. Das,<sup>59</sup> M. Guchait,<sup>59</sup> Sa. Jain,<sup>59</sup> S. Kumar,<sup>59</sup>

- M. Maity,<sup>59,v</sup> G. Majumder,<sup>59</sup> K. Mazumdar,<sup>59</sup> T. Sarkar,<sup>59,v</sup> N. Wickramage,<sup>59,w</sup> S. Chauhan,<sup>60</sup> S. Dube,<sup>60</sup> V. Hegde,<sup>60</sup> A. Kapoor,<sup>60</sup> K. Kothekar,<sup>60</sup> S. Pandey,<sup>60</sup> A. Rane,<sup>60</sup> S. Sharma,<sup>60</sup> S. Chenarani,<sup>61,x</sup> E. Eskandari Tadavani,<sup>61</sup> S. M. Etesami,<sup>61,x</sup> M. Khakzad,<sup>61</sup> M. Mohammadi Najafabadi,<sup>61</sup> M. Naseri,<sup>61</sup> S. Pakinat Mehdiabadi,<sup>61,y</sup> F. Rezaei Hosseinabadi,<sup>61</sup> B. Safarzadeh,<sup>61,z</sup> M. Zeinali,<sup>61</sup> M. Felcini,<sup>62</sup> M. Grunewald,<sup>62</sup> M. Abbrescia,<sup>63a,63b</sup> C. Calabria,<sup>63a,63b</sup> C. Caputo,<sup>63a,63b</sup> A. Colaleo,<sup>63a</sup> D. Creanza,<sup>63a,63c</sup> L. Cristella,<sup>63a,63b</sup> N. De Filippis,<sup>63a,63c</sup> M. De Palma,<sup>63a,63b</sup> L. Fiore,<sup>63a</sup> G. Iaselli,<sup>63a,63c</sup> G. Maggi,<sup>63a,63c</sup> M. Maggi,<sup>63a</sup> G. Miniello,<sup>63a,63b</sup> S. My,<sup>63a,63b</sup> S. Nuzzo,<sup>63a,63b</sup> A. Pompili,<sup>63a,63b</sup> G. Pugliese,<sup>63a,63c</sup> R. Radogna,<sup>63a,63b</sup> A. Ranieri,<sup>63a</sup> G. Selvaggi,<sup>63a,63b</sup> A. Sharma,<sup>63a</sup> L. Silvestris,<sup>63a,m</sup> R. Venditti,<sup>63a</sup> P. Verwilligen,<sup>63a</sup> G. Abbiendi,<sup>64a</sup> C. Battilana,<sup>64a</sup> D. Bonacorsi,<sup>64a,64b</sup> S. Braibant-Giacomelli,<sup>64a,64b</sup> L. Brigliadori,<sup>64a,64b</sup> R. Campanini,<sup>64a,64b</sup> P. Capiluppi,<sup>64a,64b</sup> A. Castro,<sup>64a,64b</sup> F. R. Cavallo,<sup>64a</sup> S. S. Chhibra,<sup>64a,64b</sup> M. Cuffiani,<sup>64a,64b</sup> G. M. Dallavalle,<sup>64a</sup> F. Fabbri,<sup>64a</sup> A. Fanfani,<sup>64a,64b</sup> D. Fasanella,<sup>64a,64b</sup> P. Giacomelli,<sup>64a</sup> L. Guiducci,<sup>64a,64b</sup> S. Marcellini,<sup>64a</sup> G. Masetti,<sup>64a</sup> F. L. Navarria,<sup>64a,64b</sup> A. Perrotta,<sup>64a</sup> A. M. Rossi,<sup>64a,64b</sup> T. Rovelli,<sup>64a,64b</sup> G. P. Siroli,<sup>64a,64b</sup> N. Tosi,<sup>64a,64b,m</sup> S. Albergo,<sup>65a,65b</sup> S. Costa,<sup>65a,65b</sup> A. Di Mattia,<sup>65a</sup> F. Giordano,<sup>65a,65b</sup> R. Potenza,<sup>65a,65b</sup> A. Tricomi,<sup>65a,65b</sup> C. Tuve,<sup>65a,65b</sup> G. Barbagli,<sup>66a</sup> K. Chatterjee,<sup>66a,66b</sup> V. Ciulli,<sup>66a,66b</sup> C. Civinini,<sup>66a</sup> R. D'Alessandro,<sup>66a,66b</sup> E. Focardi,<sup>66a,66b</sup> P. Lenzi,<sup>66a,66b</sup> M. Meschini,<sup>66a</sup> S. Paoletti,<sup>66a</sup> L. Russo,<sup>66a,aa</sup> G. Sguazzoni,<sup>66a</sup> D. Strom,<sup>66a</sup> L. Viliani,<sup>66a,66b,m</sup> L. Benussi,<sup>67</sup> S. Bianco,<sup>67</sup> F. Fabbri,<sup>67</sup> D. Piccolo,<sup>67</sup> F. Primavera,<sup>67,m</sup> V. Calvelli,<sup>68a,68b</sup> F. Ferro,<sup>68a</sup> E. Robutti,<sup>68a</sup> S. Tosi,<sup>68a,68b</sup> L. Brianza,<sup>69a,69b</sup> F. Brivio,<sup>69a,69b</sup> V. Ciriolo,<sup>69a,69b</sup> M. E. Dinardo,<sup>69a,69b</sup> S. Fiorendi,<sup>69a,69b</sup> S. Gennai,<sup>69a</sup> A. Ghezzi,<sup>69a,69b</sup> P. Govoni,<sup>69a,69b</sup> M. Malberti,<sup>69a,69b</sup> S. Malvezzi,<sup>69a</sup> R. A. Manzoni,<sup>69a,69b</sup> D. Menasce,<sup>69a</sup> L. Moroni,<sup>69a</sup> M. Paganoni,<sup>69a,69b</sup> K. Pauwels,<sup>69a,69b</sup> D. Pedrini,<sup>69a</sup> S. Pigazzini,<sup>69a,69b,m</sup> S. Ragazzi,<sup>69a,69b</sup> T. Tabarelli de Fatis,<sup>69a,69b</sup> S. Buontempo,<sup>70a</sup> N. Cavallo,<sup>70a,70c</sup> S. Di Guida,<sup>70a,70d,m</sup> M. Esposito,<sup>70a,70b</sup> F. Fabozzi,<sup>70a,70c</sup> F. Fienga,<sup>70a,70b</sup> A. O. M. Iorio,<sup>70a,70b</sup> W. A. Khan,<sup>70a</sup> G. Lanza,<sup>70a</sup> L. Lista,<sup>70a</sup> S. Meola,<sup>70a,70d,m</sup> P. Paolucci,<sup>70a,m</sup> C. Sciacca,<sup>70a,70b</sup> F. Thyssen,<sup>70a</sup> P. Azzi,<sup>71a,m</sup> N. Bacchetta,<sup>71a</sup> L. Benato,<sup>71a,71b</sup> D. Bisello,<sup>71a,71b</sup> A. Boletti,<sup>71a,71b</sup> R. Carlin,<sup>71a,71b</sup> A. Carvalho Antunes De Oliveira,<sup>71a,71b</sup> M. Dall'Osso,<sup>71a,71b</sup> P. De Castro Manzano,<sup>71a</sup> T. Dorigo,<sup>71a</sup> F. Gasparini,<sup>71a,71b</sup> U. Gasparini,<sup>71a,71b</sup> A. Gozzelino,<sup>71a</sup> S. Lacaprara,<sup>71a</sup> M. Margoni,<sup>71a,71b</sup> A. T. Meneguzzo,<sup>71a,71b</sup> D. Pantano,<sup>71a</sup> N. Pozzobon,<sup>71a,71b</sup> P. Ronchese,<sup>71a,71b</sup> R. Rossin,<sup>71a,71b</sup> M. Sgaravatto,<sup>71a</sup> F. Simonetto,<sup>71a,71b</sup> E. Torassa,<sup>71a</sup> S. Ventura,<sup>71a</sup> M. Zanetti,<sup>71a,71b</sup> P. Zotto,<sup>71a,71b</sup> A. Braghieri,<sup>72a</sup> F. Fallavollita,<sup>72a,72b</sup> A. Magnani,<sup>72a,72b</sup> P. Montagna,<sup>72a,72b</sup> S. P. Ratti,<sup>72a,72b</sup> V. Re,<sup>72a</sup> M. Ressegotti,<sup>72a</sup> C. Riccardi,<sup>72a,72b</sup> P. Salvini,<sup>72a</sup> I. Vai,<sup>72a,72b</sup> P. Vitulo,<sup>72a,72b</sup> L. Alunni Solestizi,<sup>73a,73b</sup> G. M. Bilei,<sup>73a</sup> D. Ciangottini,<sup>73a,73b</sup> L. Fanò,<sup>73a,73b</sup> P. Lariccia,<sup>73a,73b</sup> R. Leonardi,<sup>73a,73b</sup> G. Mantovani,<sup>73a,73b</sup> V. Mariani,<sup>73a,73b</sup> M. Menichelli,<sup>73a</sup> A. Saha,<sup>73a</sup> A. Santocchia,<sup>73a,73b</sup> D. Spiga,<sup>73a</sup> K. Androsov,<sup>74a</sup> P. Azzurri,<sup>74a,m</sup> G. Bagliesi,<sup>74a</sup> J. Bernardini,<sup>74a</sup> T. Boccali,<sup>74a</sup> L. Borrello,<sup>74a</sup> R. Castaldi,<sup>74a</sup> M. A. Ciocci,<sup>74a,74b</sup> R. Dell'Orso,<sup>74a</sup> G. Fedi,<sup>74a</sup> A. Giassi,<sup>74a</sup> M. T. Grippo,<sup>74a,aa</sup> F. Ligabue,<sup>74a,74c</sup> T. Lomtadze,<sup>74a</sup> L. Martini,<sup>74a,74b</sup> A. Messina,<sup>74a,74b</sup> F. Palla,<sup>74a</sup> A. Rizzi,<sup>74a,74b</sup> A. Savoy-Navarro,<sup>74a,bb</sup> P. Spagnolo,<sup>74a</sup> R. Tenchini,<sup>74a</sup> G. Tonelli,<sup>74a,74b</sup> A. Venturi,<sup>74a</sup> P. G. Verdini,<sup>74a</sup> L. Barone,<sup>75a,75b</sup> F. Cavallari,<sup>75a</sup> M. Cipriani,<sup>75a,75b</sup> D. Del Re,<sup>75a,75b,m</sup> M. Diemoz,<sup>75a</sup> S. Gelli,<sup>75a,75b</sup> E. Longo,<sup>75a,75b</sup> F. Margaroli,<sup>75a,75b</sup> B. Marzocchi,<sup>75a,75b</sup> P. Meridiani,<sup>75a</sup> G. Organtini,<sup>75a,75b</sup> R. Paramatti,<sup>75a,75b</sup> F. Preiato,<sup>75a,75b</sup> S. Rahatlou,<sup>75a,75b</sup> C. Rovelli,<sup>75a</sup> F. Santanastasio,<sup>75a,75b</sup> N. Amapane,<sup>76a,76b</sup> R. Arcidiacono,<sup>76a,76c,m</sup> S. Argiro,<sup>76a,76b</sup> M. Arneodo,<sup>76a,76c</sup> N. Bartosik,<sup>76a</sup> R. Bellan,<sup>76a,76b</sup> C. Biino,<sup>76a</sup> N. Cartiglia,<sup>76a</sup> F. Cenna,<sup>76a,76b</sup> M. Costa,<sup>76a,76b</sup> R. Covarelli,<sup>76a,76b</sup> A. Degano,<sup>76a,76b</sup> N. Demaria,<sup>76a</sup> B. Kiani,<sup>76a,76b</sup> C. Mariotti,<sup>76a</sup> S. Maselli,<sup>76a</sup> E. Migliore,<sup>76a,76b</sup> V. Monaco,<sup>76a,76b</sup> E. Monteil,<sup>76a,76b</sup> M. Monteno,<sup>76a</sup> M. M. Obertino,<sup>76a,76b</sup> L. Pacher,<sup>76a,76b</sup> N. Pastrone,<sup>76a</sup> M. Pelliccioni,<sup>76a</sup> G. L. Pinna Angioni,<sup>76a,76b</sup> F. Ravera,<sup>76a,76b</sup> A. Romero,<sup>76a,76b</sup> M. Ruspa,<sup>76a,76c</sup> R. Sacchi,<sup>76a,76b</sup> K. Shchelina,<sup>76a,76b</sup> V. Sola,<sup>76a</sup> A. Solano,<sup>76a,76b</sup> A. Staiano,<sup>76a</sup> P. Traczyk,<sup>76a,76b</sup> S. Belforte,<sup>77a</sup> M. Casarsa,<sup>77a</sup> F. Cossutti,<sup>77a</sup> G. Della Ricca,<sup>77a,77b</sup> A. Zanetti,<sup>77a</sup> D. H. Kim,<sup>78</sup> G. N. Kim,<sup>78</sup> M. S. Kim,<sup>78</sup> J. Lee,<sup>78</sup> S. Lee,<sup>78</sup> S. W. Lee,<sup>78</sup> Y. D. Oh,<sup>78</sup> S. Sekmen,<sup>78</sup> D. C. Son,<sup>78</sup> Y. C. Yang,<sup>78</sup> A. Lee,<sup>79</sup> H. Kim,<sup>80</sup> D. H. Moon,<sup>80</sup> J. A. Brochero Cifuentes,<sup>81</sup> J. Goh,<sup>81</sup> T. J. Kim,<sup>81</sup> S. Cho,<sup>82</sup> S. Choi,<sup>82</sup> Y. Go,<sup>82</sup> D. Gyun,<sup>82</sup> S. Ha,<sup>82</sup> B. Hong,<sup>82</sup> Y. Jo,<sup>82</sup> Y. Kim,<sup>82</sup> K. Lee,<sup>82</sup> K. S. Lee,<sup>82</sup> S. Lee,<sup>82</sup> J. Lim,<sup>82</sup> S. K. Park,<sup>82</sup> Y. Roh,<sup>82</sup> J. Almond,<sup>83</sup> J. Kim,<sup>83</sup> H. Lee,<sup>83</sup> S. B. Oh,<sup>83</sup> B. C. Radburn-Smith,<sup>83</sup> S. h. Seo,<sup>83</sup> U. K. Yang,<sup>83</sup> H. D. Yoo,<sup>83</sup> G. B. Yu,<sup>83</sup> M. Choi,<sup>84</sup> H. Kim,<sup>84</sup> J. H. Kim,<sup>84</sup> J. S. H. Lee,<sup>84</sup> I. C. Park,<sup>84</sup> G. Ryu,<sup>84</sup> Y. Choi,<sup>85</sup> C. Hwang,<sup>85</sup> J. Lee,<sup>85</sup> I. Yu,<sup>85</sup> V. Dudenias,<sup>86</sup> A. Juodagalvis,<sup>86</sup> J. Vaitkus,<sup>86</sup> I. Ahmed,<sup>87</sup> Z. A. Ibrahim,<sup>87</sup> M. A. B. Md Ali,<sup>87,cc</sup> F. Mohamad Idris,<sup>87,dd</sup> W. A. T. Wan Abdullah,<sup>87</sup> M. N. Yusli,<sup>87</sup> Z. Zolkapli,<sup>87</sup> H. Castilla-Valdez,<sup>88</sup> E. De La Cruz-Burelo,<sup>88</sup> I. Heredia-De La Cruz,<sup>88,ee</sup> R. Lopez-Fernandez,<sup>88</sup> J. Mejia Guisao,<sup>88</sup> A. Sanchez-Hernandez,<sup>88</sup> S. Carrillo Moreno,<sup>89</sup> C. Oropeza Barrera,<sup>89</sup> F. Vazquez Valencia,<sup>89</sup> I. Pedraza,<sup>90</sup> H. A. Salazar Ibarguen,<sup>90</sup> C. Uribe Estrada,<sup>90</sup> A. Morelos Pineda,<sup>91</sup> D. Krofcheck,<sup>92</sup> P. H. Butler,<sup>93</sup> A. Ahmad,<sup>94</sup> M. Ahmad,<sup>94</sup> Q. Hassan,<sup>94</sup> H. R. Hoorani,<sup>94</sup> A. Saddique,<sup>94</sup> M. A. Shah,<sup>94</sup> M. Shoaib,<sup>94</sup>

- M. Waqas,<sup>94</sup> H. Bialkowska,<sup>95</sup> M. Bluj,<sup>95</sup> B. Boimska,<sup>95</sup> T. Frueboes,<sup>95</sup> M. Górski,<sup>95</sup> M. Kazana,<sup>95</sup> K. Nawrocki,<sup>95</sup> K. Romanowska-Rybinska,<sup>95</sup> M. Szeleper,<sup>95</sup> P. Zalewski,<sup>95</sup> K. Bunkowski,<sup>96</sup> A. Byszek,<sup>96,ff</sup> K. Doroba,<sup>96</sup> A. Kalinowski,<sup>96</sup> M. Konecki,<sup>96</sup> J. Krolikowski,<sup>96</sup> M. Misiura,<sup>96</sup> M. Olszewski,<sup>96</sup> A. Pyskir,<sup>96</sup> M. Walczak,<sup>96</sup> P. Bargassa,<sup>97</sup> C. Beirão Da Cruz E Silva,<sup>97</sup> B. Calpas,<sup>97</sup> A. Di Francesco,<sup>97</sup> P. Faccioli,<sup>97</sup> M. Gallinaro,<sup>97</sup> J. Hollar,<sup>97</sup> N. Leonardo,<sup>97</sup> L. Lloret Iglesias,<sup>97</sup> M. V. Nemallapudi,<sup>97</sup> J. Seixas,<sup>97</sup> O. Toldaiev,<sup>97</sup> D. Vadrucio,<sup>97</sup> J. Varela,<sup>97</sup> S. Afanasiev,<sup>98</sup> P. Bunin,<sup>98</sup> M. Gavrilenko,<sup>98</sup> I. Golutvin,<sup>98</sup> I. Gorbunov,<sup>98</sup> A. Kamenov,<sup>98</sup> V. Karjavin,<sup>98</sup> A. Lanev,<sup>98</sup> A. Malakhov,<sup>98</sup> V. Matveev,<sup>98,gg,hh</sup> V. Palichik,<sup>98</sup> V. Perelygin,<sup>98</sup> S. Shmatov,<sup>98</sup> S. Shulha,<sup>98</sup> N. Skatchkov,<sup>98</sup> V. Smirnov,<sup>98</sup> N. Voytishin,<sup>98</sup> A. Zarubin,<sup>98</sup> Y. Ivanov,<sup>99</sup> V. Kim,<sup>99,ii</sup> E. Kuznetsova,<sup>99,jj</sup> P. Levchenko,<sup>99</sup> V. Murzin,<sup>99</sup> V. Oreshkin,<sup>99</sup> I. Smirnov,<sup>99</sup> V. Sulimov,<sup>99</sup> L. Uvarov,<sup>99</sup> S. Vavilov,<sup>99</sup> A. Vorobyev,<sup>99</sup> Yu. Andreev,<sup>100</sup> A. Dermenev,<sup>100</sup> S. Gninenko,<sup>100</sup> N. Golubev,<sup>100</sup> A. Karneyeu,<sup>100</sup> M. Kirsanov,<sup>100</sup> N. Krasnikov,<sup>100</sup> A. Pashenkov,<sup>100</sup> D. Tlisov,<sup>100</sup> A. Toropin,<sup>100</sup> V. Epshteyn,<sup>101</sup> V. Gavrilov,<sup>101</sup> N. Lychkovskaya,<sup>101</sup> V. Popov,<sup>101</sup> I. Pozdnyakov,<sup>101</sup> G. Safronov,<sup>101</sup> A. Spiridonov,<sup>101</sup> M. Toms,<sup>101</sup> E. Vlasov,<sup>101</sup> A. Zhokin,<sup>101</sup> T. Aushev,<sup>102</sup> A. Bylinkin,<sup>102,hh</sup> R. Chistov,<sup>103,kk</sup> M. Danilov,<sup>103,kk</sup> S. Polikarpov,<sup>103</sup> V. Andreev,<sup>104</sup> M. Azarkin,<sup>104,hh</sup> I. Dremin,<sup>104,hh</sup> M. Kirakosyan,<sup>104</sup> A. Terkulov,<sup>104</sup> A. Baskakov,<sup>105</sup> A. Belyaev,<sup>105</sup> E. Boos,<sup>105</sup> A. Demiyarov,<sup>105</sup> A. Ershov,<sup>105</sup> A. Gribushin,<sup>105</sup> O. Kodolova,<sup>105</sup> V. Korotkiikh,<sup>105</sup> I. Lokhtin,<sup>105</sup> I. Miagkov,<sup>105</sup> S. Obraztsov,<sup>105</sup> S. Petrushanko,<sup>105</sup> V. Savrin,<sup>105</sup> A. Snigirev,<sup>105</sup> I. Vardanyan,<sup>105</sup> V. Blinov,<sup>106,ll</sup> Y. Skovpen,<sup>106,ll</sup> D. Shtol,<sup>106,ll</sup> I. Azhgirey,<sup>107</sup> I. Bayshev,<sup>107</sup> S. Bitioukov,<sup>107</sup> D. Elumakhov,<sup>107</sup> V. Kachanov,<sup>107</sup> A. Kalinin,<sup>107</sup> D. Konstantinov,<sup>107</sup> V. Krychkin,<sup>107</sup> V. Petrov,<sup>107</sup> R. Ryutin,<sup>107</sup> A. Sobol,<sup>107</sup> S. Troshin,<sup>107</sup> N. Tyurin,<sup>107</sup> A. Uzunian,<sup>107</sup> A. Volkov,<sup>107</sup> P. Adzic,<sup>108,mm</sup> P. Cirkovic,<sup>108</sup> D. Devetak,<sup>108</sup> M. Dordevic,<sup>108</sup> J. Milosevic,<sup>108</sup> V. Rekovic,<sup>108</sup> J. Alcaraz Maestre,<sup>109</sup> M. Barrio Luna,<sup>109</sup> M. Cerrada,<sup>109</sup> N. Colino,<sup>109</sup> B. De La Cruz,<sup>109</sup> A. Delgado Peris,<sup>109</sup> A. Escalante Del Valle,<sup>109</sup> C. Fernandez Bedoya,<sup>109</sup> J. P. Fernández Ramos,<sup>109</sup> J. Flix,<sup>109</sup> M. C. Fouz,<sup>109</sup> P. Garcia-Abia,<sup>109</sup> O. Gonzalez Lopez,<sup>109</sup> S. Goy Lopez,<sup>109</sup> J. M. Hernandez,<sup>109</sup> M. I. Josa,<sup>109</sup> A. Pérez-Calero Yzquierdo,<sup>109</sup> J. Puerta Pelayo,<sup>109</sup> A. Quintario Olmeda,<sup>109</sup> I. Redondo,<sup>109</sup> L. Romero,<sup>109</sup> M. S. Soares,<sup>109</sup> J. F. de Trocóniz,<sup>110</sup> M. Missiroli,<sup>110</sup> D. Moran,<sup>110</sup> J. Cuevas,<sup>111</sup> C. Erice,<sup>111</sup> J. Fernandez Menendez,<sup>111</sup> I. Gonzalez Caballero,<sup>111</sup> J. R. González Fernández,<sup>111</sup> E. Palencia Cortezon,<sup>111</sup> S. Sanchez Cruz,<sup>111</sup> I. Suárez Andrés,<sup>111</sup> P. Vischia,<sup>111</sup> J. M. Vizan Garcia,<sup>111</sup> I. J. Cabrillo,<sup>112</sup> A. Calderon,<sup>112</sup> B. Chazin Quero,<sup>112</sup> E. Curras,<sup>112</sup> M. Fernandez,<sup>112</sup> J. Garcia-Ferrero,<sup>112</sup> G. Gomez,<sup>112</sup> A. Lopez Virto,<sup>112</sup> J. Marco,<sup>112</sup> C. Martinez Rivero,<sup>112</sup> F. Matorras,<sup>112</sup> J. Piedra Gomez,<sup>112</sup> T. Rodrigo,<sup>112</sup> A. Ruiz-Jimeno,<sup>112</sup> L. Scodellaro,<sup>112</sup> N. Trevisani,<sup>112</sup> I. Vila,<sup>112</sup> R. Vilar Cortabitarte,<sup>112</sup> D. Abbaneo,<sup>113</sup> E. Auffray,<sup>113</sup> P. Baillon,<sup>113</sup> A. H. Ball,<sup>113</sup> D. Barney,<sup>113</sup> M. Bianco,<sup>113</sup> P. Bloch,<sup>113</sup> A. Bocci,<sup>113</sup> C. Botta,<sup>113</sup> T. Camporesi,<sup>113</sup> R. Castello,<sup>113</sup> M. Cepeda,<sup>113</sup> G. Cerminara,<sup>113</sup> Y. Chen,<sup>113</sup> D. d'Enterria,<sup>113</sup> A. Dabrowski,<sup>113</sup> V. Daponte,<sup>113</sup> A. David,<sup>113</sup> M. De Gruttola,<sup>113</sup> A. De Roeck,<sup>113</sup> E. Di Marco,<sup>113,nn</sup> M. Dobson,<sup>113</sup> B. Dorney,<sup>113</sup> T. du Pree,<sup>113</sup> M. Dünser,<sup>113</sup> N. Dupont,<sup>113</sup> A. Elliott-Peisert,<sup>113</sup> P. Everaerts,<sup>113</sup> G. Franzoni,<sup>113</sup> J. Fulcher,<sup>113</sup> W. Funk,<sup>113</sup> D. Gigi,<sup>113</sup> K. Gill,<sup>113</sup> F. Glege,<sup>113</sup> D. Gulhan,<sup>113</sup> S. Gundacker,<sup>113</sup> M. Guthoff,<sup>113</sup> P. Harris,<sup>113</sup> J. Hegeman,<sup>113</sup> V. Innocente,<sup>113</sup> P. Janot,<sup>113</sup> O. Karacheban,<sup>113,p</sup> J. Kieseler,<sup>113</sup> H. Kirschenmann,<sup>113</sup> V. Knünz,<sup>113</sup> A. Kornmayer,<sup>113,m</sup> M. J. Kortelainen,<sup>113</sup> C. Lange,<sup>113</sup> P. Lecoq,<sup>113</sup> C. Lourenço,<sup>113</sup> M. T. Lucchini,<sup>113</sup> L. Malgeri,<sup>113</sup> M. Mannelli,<sup>113</sup> A. Martelli,<sup>113</sup> F. Meijers,<sup>113</sup> J. A. Merlin,<sup>113</sup> S. Mersi,<sup>113</sup> E. Meschi,<sup>113</sup> P. Milenovic,<sup>113,oo</sup> F. Moortgat,<sup>113</sup> M. Mulders,<sup>113</sup> H. Neugebauer,<sup>113</sup> S. Orfanelli,<sup>113</sup> L. Orsini,<sup>113</sup> L. Pape,<sup>113</sup> E. Perez,<sup>113</sup> M. Peruzzi,<sup>113</sup> A. Petrilli,<sup>113</sup> G. Petrucciani,<sup>113</sup> A. Pfeiffer,<sup>113</sup> M. Pierini,<sup>113</sup> A. Racz,<sup>113</sup> T. Reis,<sup>113</sup> G. Rolandi,<sup>113,pp</sup> M. Rovere,<sup>113</sup> H. Sakulin,<sup>113</sup> J. B. Sauvan,<sup>113</sup> C. Schäfer,<sup>113</sup> C. Schwick,<sup>113</sup> M. Seidel,<sup>113</sup> A. Sharma,<sup>113</sup> P. Silva,<sup>113</sup> P. Sphicas,<sup>113,qq</sup> J. Steggemann,<sup>113</sup> M. Stoye,<sup>113</sup> M. Tosi,<sup>113</sup> D. Treille,<sup>113</sup> A. Triossi,<sup>113</sup> A. Tsiros,<sup>113</sup> V. Veckalns,<sup>113,rr</sup> G. I. Veres,<sup>113,r</sup> M. Verweij,<sup>113</sup> N. Wardle,<sup>113</sup> A. Zagozdinska,<sup>113,ff</sup> W. D. Zeuner,<sup>113</sup> W. Bertl,<sup>114</sup> K. Deiters,<sup>114</sup> W. Erdmann,<sup>114</sup> R. Horisberger,<sup>114</sup> Q. Ingram,<sup>114</sup> H. C. Kaestli,<sup>114</sup> D. Kotlinski,<sup>114</sup> U. Langenegger,<sup>114</sup> T. Rohe,<sup>114</sup> S. A. Wiederkehr,<sup>114</sup> F. Bachmair,<sup>115</sup> L. Bäni,<sup>115</sup> P. Berger,<sup>115</sup> L. Bianchini,<sup>115</sup> B. Casal,<sup>115</sup> G. Dissertori,<sup>115</sup> M. Dittmar,<sup>115</sup> M. Donegà,<sup>115</sup> C. Grab,<sup>115</sup> C. Heidegger,<sup>115</sup> D. Hits,<sup>115</sup> J. Hoss,<sup>115</sup> G. Kasieczka,<sup>115</sup> T. Klijsma,<sup>115</sup> W. Lustermann,<sup>115</sup> B. Mangano,<sup>115</sup> M. Marionneau,<sup>115</sup> P. Martinez Ruiz del Arbol,<sup>115</sup> M. Masciovecchio,<sup>115</sup> M. T. Meinhard,<sup>115</sup> D. Meister,<sup>115</sup> F. Micheli,<sup>115</sup> P. Musella,<sup>115</sup> F. Nessi-Tedaldi,<sup>115</sup> F. Pandolfi,<sup>115</sup> J. Pata,<sup>115</sup> F. Pauss,<sup>115</sup> G. Perrin,<sup>115</sup> L. Perrozzi,<sup>115</sup> M. Quittnat,<sup>115</sup> M. Rossini,<sup>115</sup> M. Schönenberger,<sup>115</sup> A. Starodumov,<sup>115,ss</sup> V. R. Tavolaro,<sup>115</sup> K. Theofilatos,<sup>115</sup> M. L. Vesterbacka Olsson,<sup>115</sup> R. Wallny,<sup>115</sup> D. H. Zhu,<sup>115</sup> T. K. Aarrestad,<sup>116</sup> C. Amsler,<sup>116,tt</sup> L. Caminada,<sup>116</sup> M. F. Canelli,<sup>116</sup> A. De Cosa,<sup>116</sup> S. Donato,<sup>116</sup> C. Galloni,<sup>116</sup> A. Hinzmann,<sup>116</sup> T. Hreus,<sup>116</sup> B. Kilminster,<sup>116</sup> J. Ngadiuba,<sup>116</sup> D. Pinna,<sup>116</sup> G. Raucó,<sup>116</sup> P. Robmann,<sup>116</sup> D. Salerno,<sup>116</sup> C. Seitz,<sup>116</sup> Y. Yang,<sup>116</sup> A. Zucchetta,<sup>116</sup> V. Candelise,<sup>117</sup> T. H. Doan,<sup>117</sup> Sh. Jain,<sup>117</sup> R. Khurana,<sup>117</sup>

M. Konyushikhin,<sup>117</sup> C. M. Kuo,<sup>117</sup> W. Lin,<sup>117</sup> A. Pozdnyakov,<sup>117</sup> S. S. Yu,<sup>117</sup> Arun Kumar,<sup>118</sup> P. Chang,<sup>118</sup> Y. H. Chang,<sup>118</sup> Y. Chao,<sup>118</sup> K. F. Chen,<sup>118</sup> P. H. Chen,<sup>118</sup> F. Fiori,<sup>118</sup> W.-S. Hou,<sup>118</sup> Y. Hsiung,<sup>118</sup> Y. F. Liu,<sup>118</sup> R.-S. Lu,<sup>118</sup> M. Miñano Moya,<sup>118</sup> E. Paganis,<sup>118</sup> A. Psallidas,<sup>118</sup> J. f. Tsai,<sup>118</sup> B. Asavapibhop,<sup>119</sup> K. Kovitanggoon,<sup>119</sup> G. Singh,<sup>119</sup> N. Srimanobhas,<sup>119</sup> A. Adiguzel,<sup>120,uu</sup> F. Boran,<sup>120</sup> S. Damarseckin,<sup>120</sup> Z. S. Demiroglu,<sup>120</sup> C. Dozen,<sup>120</sup> E. Eskut,<sup>120</sup> S. Girgis,<sup>120</sup> G. Gokbulut,<sup>120</sup> Y. Guler,<sup>120</sup> I. Hos,<sup>120,vv</sup> E. E. Kangal,<sup>120,ww</sup> O. Kara,<sup>120</sup> A. Kayis Topaksu,<sup>120</sup> U. Kiminsu,<sup>120</sup> M. Oglakci,<sup>120</sup> G. Onengut,<sup>120,xx</sup> K. Ozdemir,<sup>120,yy</sup> S. Ozturk,<sup>120,zz</sup> A. Polatoz,<sup>120</sup> B. Tali,<sup>120,aaa</sup> S. Turkcapar,<sup>120</sup> I. S. Zorbakir,<sup>120</sup> C. Zorbilmez,<sup>120</sup> B. Bilin,<sup>121</sup> G. Karapinar,<sup>121,bbb</sup> K. Ocalan,<sup>121,ccc</sup> M. Yalvac,<sup>121</sup> M. Zeyrek,<sup>121</sup> E. Gülmez,<sup>122</sup> M. Kaya,<sup>122,ddd</sup> O. Kaya,<sup>122,eee</sup> E. A. Yetkin,<sup>122,fff</sup> A. Cakir,<sup>123</sup> K. Cankocak,<sup>123</sup> B. Grynyov,<sup>124</sup> L. Levchuk,<sup>125</sup> P. Sorokin,<sup>125</sup> R. Aggleton,<sup>126</sup> F. Ball,<sup>126</sup> L. Beck,<sup>126</sup> J. J. Brooke,<sup>126</sup> D. Burns,<sup>126</sup> E. Clement,<sup>126</sup> D. Cussans,<sup>126</sup> H. Flacher,<sup>126</sup> J. Goldstein,<sup>126</sup> M. Grimes,<sup>126</sup> G. P. Heath,<sup>126</sup> H. F. Heath,<sup>126</sup> J. Jacob,<sup>126</sup> L. Kreczko,<sup>126</sup> C. Lucas,<sup>126</sup> D. M. Newbold,<sup>126,ggg</sup> S. Paramesvaran,<sup>126</sup> A. Poll,<sup>126</sup> T. Sakuma,<sup>126</sup> S. Seif El Nasr-storey,<sup>126</sup> D. Smith,<sup>126</sup> V. J. Smith,<sup>126</sup> A. Belyaev,<sup>127,hhh</sup> C. Brew,<sup>127</sup> R. M. Brown,<sup>127</sup> L. Calligaris,<sup>127</sup> D. Cieri,<sup>127</sup> D. J. A. Cockerill,<sup>127</sup> J. A. Coughlan,<sup>127</sup> K. Harder,<sup>127</sup> S. Harper,<sup>127</sup> E. Olaiya,<sup>127</sup> D. Petyt,<sup>127</sup> C. H. Shepherd-Themistocleous,<sup>127</sup> A. Thea,<sup>127</sup> I. R. Tomalin,<sup>127</sup> T. Williams,<sup>127</sup> M. Baber,<sup>128</sup> R. Bainbridge,<sup>128</sup> O. Buchmuller,<sup>128</sup> A. Bundock,<sup>128</sup> S. Casasso,<sup>128</sup> M. Citron,<sup>128</sup> D. Colling,<sup>128</sup> L. Corpe,<sup>128</sup> P. Dauncey,<sup>128</sup> G. Davies,<sup>128</sup> A. De Wit,<sup>128</sup> M. Della Negra,<sup>128</sup> R. Di Maria,<sup>128</sup> P. Dunne,<sup>128</sup> A. Elwood,<sup>128</sup> D. Futyan,<sup>128</sup> Y. Haddad,<sup>128</sup> G. Hall,<sup>128</sup> G. Iles,<sup>128</sup> T. James,<sup>128</sup> R. Lane,<sup>128</sup> C. Laner,<sup>128</sup> L. Lyons,<sup>128</sup> A.-M. Magnan,<sup>128</sup> S. Malik,<sup>128</sup> L. Mastrolorenzo,<sup>128</sup> J. Nash,<sup>128</sup> A. Nikitenko,<sup>128,ss</sup> J. Pela,<sup>128</sup> M. Pesaresi,<sup>128</sup> D. M. Raymond,<sup>128</sup> A. Richards,<sup>128</sup> A. Rose,<sup>128</sup> E. Scott,<sup>128</sup> C. Seez,<sup>128</sup> S. Summers,<sup>128</sup> A. Tapper,<sup>128</sup> K. Uchida,<sup>128</sup> M. Vazquez Acosta,<sup>128,iii</sup> T. Virdee,<sup>128,m</sup> J. Wright,<sup>128</sup> S. C. Zenz,<sup>128</sup> J. E. Cole,<sup>129</sup> P. R. Hobson,<sup>129</sup> A. Khan,<sup>129</sup> P. Kyberd,<sup>129</sup> I. D. Reid,<sup>129</sup> P. Symonds,<sup>129</sup> L. Teodorescu,<sup>129</sup> M. Turner,<sup>129</sup> A. Borzou,<sup>130</sup> K. Call,<sup>130</sup> J. Dittmann,<sup>130</sup> K. Hatakeyama,<sup>130</sup> H. Liu,<sup>130</sup> N. Pastika,<sup>130</sup> R. Bartek,<sup>131</sup> A. Dominguez,<sup>131</sup> A. Buccilli,<sup>132</sup> S. I. Cooper,<sup>132</sup> C. Henderson,<sup>132</sup> P. Rumerio,<sup>132</sup> C. West,<sup>132</sup> D. Arcaro,<sup>133</sup> A. Avetisyan,<sup>133</sup> T. Bose,<sup>133</sup> D. Gastler,<sup>133</sup> D. Rankin,<sup>133</sup> C. Richardson,<sup>133</sup> J. Rohlf,<sup>133</sup> L. Sulak,<sup>133</sup> D. Zou,<sup>133</sup> G. Benelli,<sup>134</sup> D. Cutts,<sup>134</sup> A. Garabedian,<sup>134</sup> J. Hakala,<sup>134</sup> U. Heintz,<sup>134</sup> J. M. Hogan,<sup>134</sup> K. H. M. Kwok,<sup>134</sup> E. Laird,<sup>134</sup> G. Landsberg,<sup>134</sup> Z. Mao,<sup>134</sup> M. Narain,<sup>134</sup> S. Piperov,<sup>134</sup> S. Sagir,<sup>134</sup> E. Spencer,<sup>134</sup> R. Syarif,<sup>134</sup> R. Band,<sup>135</sup> C. Brainerd,<sup>135</sup> D. Burns,<sup>135</sup> M. Calderon De La Barca Sanchez,<sup>135</sup> M. Chertok,<sup>135</sup> J. Conway,<sup>135</sup> R. Conway,<sup>135</sup> P. T. Cox,<sup>135</sup> R. Erbacher,<sup>135</sup> C. Flores,<sup>135</sup> G. Funk,<sup>135</sup> M. Gardner,<sup>135</sup> W. Ko,<sup>135</sup> R. Lander,<sup>135</sup> C. Mclean,<sup>135</sup> M. Mulhearn,<sup>135</sup> D. Pellett,<sup>135</sup> J. Pilot,<sup>135</sup> S. Shalhout,<sup>135</sup> M. Shi,<sup>135</sup> J. Smith,<sup>135</sup> M. Squires,<sup>135</sup> D. Stolp,<sup>135</sup> K. Tos,<sup>135</sup> M. Tripathi,<sup>135</sup> Z. Wang,<sup>135</sup> M. Bachtis,<sup>136</sup> C. Bravo,<sup>136</sup> R. Cousins,<sup>136</sup> A. Dasgupta,<sup>136</sup> A. Florent,<sup>136</sup> J. Hauser,<sup>136</sup> M. Ignatenko,<sup>136</sup> N. Mccoll,<sup>136</sup> D. Saltzberg,<sup>136</sup> C. Schnaible,<sup>136</sup> V. Valuev,<sup>136</sup> E. Bouvier,<sup>137</sup> K. Burt,<sup>137</sup> R. Clare,<sup>137</sup> J. Ellison,<sup>137</sup> J. W. Gary,<sup>137</sup> S. M. A. Ghiasi Shirazi,<sup>137</sup> G. Hanson,<sup>137</sup> J. Heilman,<sup>137</sup> P. Jandir,<sup>137</sup> E. Kennedy,<sup>137</sup> F. Lacroix,<sup>137</sup> O. R. Long,<sup>137</sup> M. Olmedo Negrete,<sup>137</sup> M. I. Paneva,<sup>137</sup> A. Shrinivas,<sup>137</sup> W. Si,<sup>137</sup> H. Wei,<sup>137</sup> S. Wimpenny,<sup>137</sup> B. R. Yates,<sup>137</sup> J. G. Branson,<sup>138</sup> G. B. Cerati,<sup>138</sup> S. Cittolin,<sup>138</sup> M. Derdzinski,<sup>138</sup> A. Holzner,<sup>138</sup> D. Klein,<sup>138</sup> G. Kole,<sup>138</sup> V. Krutelyov,<sup>138</sup> J. Letts,<sup>138</sup> I. Macneill,<sup>138</sup> D. Olivito,<sup>138</sup> S. Padhi,<sup>138</sup> M. Pieri,<sup>138</sup> M. Sani,<sup>138</sup> V. Sharma,<sup>138</sup> S. Simon,<sup>138</sup> M. Tadel,<sup>138</sup> A. Vartak,<sup>138</sup> S. Wasserbaech,<sup>138,iii</sup> F. Würthwein,<sup>138</sup> A. Yagil,<sup>138</sup> G. Zevi Della Porta,<sup>138</sup> N. Amin,<sup>139</sup> R. Bhandari,<sup>139</sup> J. Bradmiller-Feld,<sup>139</sup> C. Campagnari,<sup>139</sup> A. Dishaw,<sup>139</sup> V. Dutta,<sup>139</sup> M. Franco Sevilla,<sup>139</sup> C. George,<sup>139</sup> F. Golf,<sup>139</sup> L. Gouskos,<sup>139</sup> J. Gran,<sup>139</sup> R. Heller,<sup>139</sup> J. Incandela,<sup>139</sup> S. D. Mullin,<sup>139</sup> A. Ovcharova,<sup>139</sup> H. Qu,<sup>139</sup> J. Richman,<sup>139</sup> D. Stuart,<sup>139</sup> I. Suarez,<sup>139</sup> J. Yoo,<sup>139</sup> D. Anderson,<sup>140</sup> J. Bendavid,<sup>140</sup> A. Bornheim,<sup>140</sup> J. M. Lawhorn,<sup>140</sup> H. B. Newman,<sup>140</sup> C. Pena,<sup>140</sup> M. Spiropulu,<sup>140</sup> J. R. Vlimant,<sup>140</sup> S. Xie,<sup>140</sup> R. Y. Zhu,<sup>140</sup> M. B. Andrews,<sup>141</sup> T. Ferguson,<sup>141</sup> M. Paulini,<sup>141</sup> J. Russ,<sup>141</sup> M. Sun,<sup>141</sup> H. Vogel,<sup>141</sup> I. Vorobiev,<sup>141</sup> M. Weinberg,<sup>141</sup> J. P. Cumalat,<sup>142</sup> W. T. Ford,<sup>142</sup> F. Jensen,<sup>142</sup> A. Johnson,<sup>142</sup> M. Krohn,<sup>142</sup> S. Leontsinis,<sup>142</sup> T. Mulholland,<sup>142</sup> K. Stenson,<sup>142</sup> S. R. Wagner,<sup>142</sup> J. Alexander,<sup>143</sup> J. Chaves,<sup>143</sup> J. Chu,<sup>143</sup> S. Dittmer,<sup>143</sup> K. McDermott,<sup>143</sup> N. Mirman,<sup>143</sup> J. R. Patterson,<sup>143</sup> A. Rinkevicius,<sup>143</sup> A. Ryd,<sup>143</sup> L. Skinnari,<sup>143</sup> L. Soffi,<sup>143</sup> S. M. Tan,<sup>143</sup> Z. Tao,<sup>143</sup> J. Thom,<sup>143</sup> J. Tucker,<sup>143</sup> P. Wittich,<sup>143</sup> M. Zientek,<sup>143</sup> D. Winn,<sup>144</sup> S. Abdullin,<sup>145</sup> M. Albrow,<sup>145</sup> G. Apollinari,<sup>145</sup> A. Apresyan,<sup>145</sup> A. Apyan,<sup>145</sup> S. Banerjee,<sup>145</sup> L. A. T. Bauerdick,<sup>145</sup> A. Beretvas,<sup>145</sup> J. Berryhill,<sup>145</sup> P. C. Bhat,<sup>145</sup> G. Bolla,<sup>145</sup> K. Burkett,<sup>145</sup> J. N. Butler,<sup>145</sup> A. Canepa,<sup>145</sup> H. W. K. Cheung,<sup>145</sup> F. Chlebana,<sup>145</sup> M. Cremonesi,<sup>145</sup> J. Duarte,<sup>145</sup> V. D. Elvira,<sup>145</sup> I. Fisk,<sup>145</sup> J. Freeman,<sup>145</sup> Z. Gecse,<sup>145</sup> E. Gottschalk,<sup>145</sup> L. Gray,<sup>145</sup> D. Green,<sup>145</sup> S. Grünendahl,<sup>145</sup> O. Gutsche,<sup>145</sup> R. M. Harris,<sup>145</sup> S. Hasegawa,<sup>145</sup> J. Hirschauer,<sup>145</sup> Z. Hu,<sup>145</sup> B. Jayatilaka,<sup>145</sup> S. Jindariani,<sup>145</sup> M. Johnson,<sup>145</sup> U. Joshi,<sup>145</sup> B. Klima,<sup>145</sup> B. Kreis,<sup>145</sup> S. Lammel,<sup>145</sup> D. Lincoln,<sup>145</sup> R. Lipton,<sup>145</sup> M. Liu,<sup>145</sup> T. Liu,<sup>145</sup> R. Lopes De Sá,<sup>145</sup> J. Lykken,<sup>145</sup> K. Maeshima,<sup>145</sup> N. Magini,<sup>145</sup> J. M. Marraffino,<sup>145</sup> S. Maruyama,<sup>145</sup> D. Mason,<sup>145</sup> P. McBride,<sup>145</sup> P. Merkel,<sup>145</sup> S. Mrenna,<sup>145</sup> S. Nahn,<sup>145</sup> V. O'Dell,<sup>145</sup> K. Pedro,<sup>145</sup> O. Prokofyev,<sup>145</sup> G. Rakness,<sup>145</sup> L. Ristori,<sup>145</sup>



B. Schneider,<sup>145</sup> E. Sexton-Kennedy,<sup>145</sup> A. Soha,<sup>145</sup> W. J. Spalding,<sup>145</sup> L. Spiegel,<sup>145</sup> S. Stoynev,<sup>145</sup> J. Strait,<sup>145</sup> N. Strobbe,<sup>145</sup> L. Taylor,<sup>145</sup> S. Tkaczyk,<sup>145</sup> N. V. Tran,<sup>145</sup> L. Uplegger,<sup>145</sup> E. W. Vaandering,<sup>145</sup> C. Vernieri,<sup>145</sup> M. Verzocchi,<sup>145</sup> R. Vidal,<sup>145</sup> M. Wang,<sup>145</sup> H. A. Weber,<sup>145</sup> A. Whitbeck,<sup>145</sup> D. Acosta,<sup>146</sup> P. Avery,<sup>146</sup> P. Bortignon,<sup>146</sup> A. Brinkerhoff,<sup>146</sup> A. Carnes,<sup>146</sup> M. Carver,<sup>146</sup> D. Curry,<sup>146</sup> S. Das,<sup>146</sup> R. D. Field,<sup>146</sup> I. K. Furic,<sup>146</sup> J. Konigsberg,<sup>146</sup> A. Korytov,<sup>146</sup> K. Kotov,<sup>146</sup> P. Ma,<sup>146</sup> K. Matchev,<sup>146</sup> H. Mei,<sup>146</sup> G. Mitselmakher,<sup>146</sup> D. Rank,<sup>146</sup> L. Shchutska,<sup>146</sup> D. Sperka,<sup>146</sup> N. Terentyev,<sup>146</sup> L. Thomas,<sup>146</sup> J. Wang,<sup>146</sup> S. Wang,<sup>146</sup> J. Yelton,<sup>146</sup> S. Linn,<sup>147</sup> P. Markowitz,<sup>147</sup> G. Martinez,<sup>147</sup> J. L. Rodriguez,<sup>147</sup> A. Ackert,<sup>148</sup> T. Adams,<sup>148</sup> A. Askew,<sup>148</sup> S. Hagopian,<sup>148</sup> V. Hagopian,<sup>148</sup> K. F. Johnson,<sup>148</sup> T. Kolberg,<sup>148</sup> T. Perry,<sup>148</sup> H. Prosper,<sup>148</sup> A. Santra,<sup>148</sup> R. Yohay,<sup>148</sup> M. M. Baarmand,<sup>149</sup> V. Bhopatkar,<sup>149</sup> S. Colafranceschi,<sup>149</sup> M. Hohlmann,<sup>149</sup> D. Noonan,<sup>149</sup> T. Roy,<sup>149</sup> F. Yumiceva,<sup>149</sup> M. R. Adams,<sup>150</sup> L. Apanasevich,<sup>150</sup> D. Berry,<sup>150</sup> R. R. Betts,<sup>150</sup> R. Cavanaugh,<sup>150</sup> X. Chen,<sup>150</sup> O. Evdokimov,<sup>150</sup> C. E. Gerber,<sup>150</sup> D. A. Hangal,<sup>150</sup> D. J. Hofman,<sup>150</sup> K. Jung,<sup>150</sup> J. Kamin,<sup>150</sup> I. D. Sandoval Gonzalez,<sup>150</sup> M. B. Tonjes,<sup>150</sup> H. Trauger,<sup>150</sup> N. Varelas,<sup>150</sup> H. Wang,<sup>150</sup> Z. Wu,<sup>150</sup> J. Zhang,<sup>150</sup> B. Bilki,<sup>151,kkk</sup> W. Clarida,<sup>151</sup> K. Dilsiz,<sup>151,lll</sup> S. Durgut,<sup>151</sup> R. P. Gandrajula,<sup>151</sup> M. Haytmyradov,<sup>151</sup> V. Khristenko,<sup>151</sup> J.-P. Merlo,<sup>151</sup> H. Mermerkaya,<sup>151,mmm</sup> A. Mestvirishvili,<sup>151</sup> A. Moeller,<sup>151</sup> J. Nachtman,<sup>151</sup> H. Ogul,<sup>151,nnn</sup> Y. Onel,<sup>151</sup> F. Ozok,<sup>151,ooo</sup> A. Penzo,<sup>151</sup> C. Snyder,<sup>151</sup> E. Tiras,<sup>151</sup> J. Wetzel,<sup>151</sup> K. Yi,<sup>151</sup> B. Blumenfeld,<sup>152</sup> A. Cocoros,<sup>152</sup> N. Eminizer,<sup>152</sup> D. Fehling,<sup>152</sup> L. Feng,<sup>152</sup> A. V. Gritsan,<sup>152</sup> P. Maksimovic,<sup>152</sup> J. Roskes,<sup>152</sup> U. Sarica,<sup>152</sup> M. Swartz,<sup>152</sup> M. Xiao,<sup>152</sup> C. You,<sup>152</sup> A. Al-bataineh,<sup>153</sup> P. Baringer,<sup>153</sup> A. Bean,<sup>153</sup> S. Boren,<sup>153</sup> J. Bowen,<sup>153</sup> J. Castle,<sup>153</sup> S. Khalil,<sup>153</sup> A. Kropivnitskaya,<sup>153</sup> D. Majumder,<sup>153</sup> W. Mcbrayer,<sup>153</sup> M. Murray,<sup>153</sup> C. Royon,<sup>153</sup> S. Sanders,<sup>153</sup> R. Stringer,<sup>153</sup> J. D. Tapia Takaki,<sup>153</sup> Q. Wang,<sup>153</sup> A. Ivanov,<sup>154</sup> K. Kaadze,<sup>154</sup> Y. Maravin,<sup>154</sup> A. Mohammadi,<sup>154</sup> L. K. Saini,<sup>154</sup> N. Skhirtladze,<sup>154</sup> S. Toda,<sup>154</sup> F. Rebassoo,<sup>155</sup> D. Wright,<sup>155</sup> C. Anelli,<sup>156</sup> A. Baden,<sup>156</sup> O. Baron,<sup>156</sup> A. Belloni,<sup>156</sup> B. Calvert,<sup>156</sup> S. C. Eno,<sup>156</sup> C. Ferraioli,<sup>156</sup> N. J. Hadley,<sup>156</sup> S. Jabeen,<sup>156</sup> G. Y. Jeng,<sup>156</sup> R. G. Kellogg,<sup>156</sup> J. Kunkle,<sup>156</sup> A. C. Mignerey,<sup>156</sup> F. Ricci-Tam,<sup>156</sup> Y. H. Shin,<sup>156</sup> A. Skuja,<sup>156</sup> S. C. Tonwar,<sup>156</sup> D. Abercrombie,<sup>157</sup> B. Allen,<sup>157</sup> V. Azzolini,<sup>157</sup> R. Barbieri,<sup>157</sup> A. Baty,<sup>157</sup> R. Bi,<sup>157</sup> K. Bierwagen,<sup>157</sup> S. Brandt,<sup>157</sup> W. Busza,<sup>157</sup> I. A. Cali,<sup>157</sup> M. D'Alfonso,<sup>157</sup> Z. Demiragli,<sup>157</sup> G. Gomez Ceballos,<sup>157</sup> M. Goncharov,<sup>157</sup> D. Hsu,<sup>157</sup> Y. Iiyama,<sup>157</sup> G. M. Innocenti,<sup>157</sup> M. Klute,<sup>157</sup> D. Kovalskyi,<sup>157</sup> Y. S. Lai,<sup>157</sup> Y.-J. Lee,<sup>157</sup> A. Levin,<sup>157</sup> P. D. Luckey,<sup>157</sup> B. Maier,<sup>157</sup> A. C. Marini,<sup>157</sup> C. McGinn,<sup>157</sup> C. Mironov,<sup>157</sup> S. Narayanan,<sup>157</sup> X. Niu,<sup>157</sup> C. Paus,<sup>157</sup> C. Roland,<sup>157</sup> G. Roland,<sup>157</sup> J. Salfeld-Nebgen,<sup>157</sup> G. S. F. Stephans,<sup>157</sup> K. Tatar,<sup>157</sup> A. Turner,<sup>157</sup> D. Velicanu,<sup>157</sup> J. Wang,<sup>157</sup> T. W. Wang,<sup>157</sup> B. Wyslouch,<sup>157</sup> A. C. Benvenuti,<sup>158</sup> R. M. Chatterjee,<sup>158</sup> A. Evans,<sup>158</sup> P. Hansen,<sup>158</sup> S. Kalafut,<sup>158</sup> S. C. Kao,<sup>158</sup> Y. Kubota,<sup>158</sup> Z. Lesko,<sup>158</sup> J. Mans,<sup>158</sup> S. Nourbakhsh,<sup>158</sup> N. Ruckstuhl,<sup>158</sup> R. Rusack,<sup>158</sup> N. Tambe,<sup>158</sup> J. Turkewitz,<sup>158</sup> J. G. Acosta,<sup>159</sup> S. Oliveros,<sup>159</sup> E. Avdeeva,<sup>160</sup> K. Bloom,<sup>160</sup> D. R. Claes,<sup>160</sup> C. Fangmeier,<sup>160</sup> R. Gonzalez Suarez,<sup>160</sup> R. Kamalieddin,<sup>160</sup> I. Kravchenko,<sup>160</sup> J. Monroy,<sup>160</sup> J. E. Siado,<sup>160</sup> G. R. Snow,<sup>160</sup> B. Stieger,<sup>160</sup> M. Alyari,<sup>161</sup> J. Dolen,<sup>161</sup> A. Godshalk,<sup>161</sup> C. Harrington,<sup>161</sup> I. Iashvili,<sup>161</sup> A. Kharchilava,<sup>161</sup> A. Parker,<sup>161</sup> S. Rappoccio,<sup>161</sup> B. Roozbahani,<sup>161</sup> G. Alverson,<sup>162</sup> E. Barberis,<sup>162</sup> A. Hortiangtham,<sup>162</sup> A. Massironi,<sup>162</sup> D. M. Morse,<sup>162</sup> D. Nash,<sup>162</sup> T. Orimoto,<sup>162</sup> R. Teixeira De Lima,<sup>162</sup> D. Trocino,<sup>162</sup> R.-J. Wang,<sup>162</sup> D. Wood,<sup>162</sup> S. Bhattacharya,<sup>163</sup> O. Charaf,<sup>163</sup> K. A. Hahn,<sup>163</sup> N. Mucia,<sup>163</sup> N. Odell,<sup>163</sup> B. Pollack,<sup>163</sup> M. H. Schmitt,<sup>163</sup> K. Sung,<sup>163</sup> M. Trovato,<sup>163</sup> M. Velasco,<sup>163</sup> N. Dev,<sup>164</sup> M. Hildreth,<sup>164</sup> K. Hurtado Anampa,<sup>164</sup> C. Jessop,<sup>164</sup> D. J. Karmgard,<sup>164</sup> N. Kellams,<sup>164</sup> K. Lannon,<sup>164</sup> N. Loukas,<sup>164</sup> N. Marinelli,<sup>164</sup> F. Meng,<sup>164</sup> C. Mueller,<sup>164</sup> Y. Musienko,<sup>164,gg</sup> M. Planer,<sup>164</sup> A. Reinsvold,<sup>164</sup> R. Ruchti,<sup>164</sup> N. Rupprecht,<sup>164</sup> G. Smith,<sup>164</sup> S. Taroni,<sup>164</sup> M. Wayne,<sup>164</sup> M. Wolf,<sup>164</sup> A. Woodard,<sup>164</sup> J. Alimena,<sup>165</sup> L. Antonelli,<sup>165</sup> B. Bylsma,<sup>165</sup> L. S. Durkin,<sup>165</sup> S. Flowers,<sup>165</sup> B. Francis,<sup>165</sup> A. Hart,<sup>165</sup> C. Hill,<sup>165</sup> W. Ji,<sup>165</sup> B. Liu,<sup>165</sup> W. Luo,<sup>165</sup> D. Puigh,<sup>165</sup> B. L. Winer,<sup>165</sup> H. W. Wulsin,<sup>165</sup> A. Benaglia,<sup>166</sup> S. Cooperstein,<sup>166</sup> O. Driga,<sup>166</sup> P. Elmer,<sup>166</sup> J. Hardenbrook,<sup>166</sup> P. Hebda,<sup>166</sup> D. Lange,<sup>166</sup> J. Luo,<sup>166</sup> D. Marlow,<sup>166</sup> K. Mei,<sup>166</sup> I. Ojalvo,<sup>166</sup> J. Olsen,<sup>166</sup> C. Palmer,<sup>166</sup> P. Piroué,<sup>166</sup> D. Stickland,<sup>166</sup> A. Svyatkovskiy,<sup>166</sup> C. Tully,<sup>166</sup> S. Malik,<sup>167</sup> S. Norberg,<sup>167</sup> A. Barker,<sup>168</sup> V. E. Barnes,<sup>168</sup> S. Folgueras,<sup>168</sup> L. Gutay,<sup>168</sup> M. K. Jha,<sup>168</sup> M. Jones,<sup>168</sup> A. W. Jung,<sup>168</sup> A. Khatiwada,<sup>168</sup> D. H. Miller,<sup>168</sup> N. Neumeister,<sup>168</sup> J. F. Schulte,<sup>168</sup> J. Sun,<sup>168</sup> F. Wang,<sup>168</sup> W. Xie,<sup>168</sup> T. Cheng,<sup>169</sup> N. Parashar,<sup>169</sup> J. Stupak,<sup>169</sup> A. Adair,<sup>170</sup> B. Akgun,<sup>170</sup> Z. Chen,<sup>170</sup> K. M. Ecklund,<sup>170</sup> F. J. M. Geurts,<sup>170</sup> M. Guilbaud,<sup>170</sup> W. Li,<sup>170</sup> B. Michlin,<sup>170</sup> M. Northup,<sup>170</sup> B. P. Padley,<sup>170</sup> J. Roberts,<sup>170</sup> J. Rorie,<sup>170</sup> Z. Tu,<sup>170</sup> J. Zabel,<sup>170</sup> B. Betchart,<sup>171</sup> A. Bodek,<sup>171</sup> P. de Barbaro,<sup>171</sup> R. Demina,<sup>171</sup> Y. t. Duh,<sup>171</sup> T. Ferbel,<sup>171</sup> M. Galanti,<sup>171</sup> A. Garcia-Bellido,<sup>171</sup> J. Han,<sup>171</sup> O. Hindrichs,<sup>171</sup> A. Khukhunaishvili,<sup>171</sup> K. H. Lo,<sup>171</sup> P. Tan,<sup>171</sup> M. Verzetti,<sup>171</sup> R. Ciesielski,<sup>172</sup> K. Goulianos,<sup>172</sup> C. Mesropian,<sup>172</sup> A. Agapitos,<sup>173</sup> J. P. Chou,<sup>173</sup> Y. Gershtein,<sup>173</sup> T. A. Gómez Espinosa,<sup>173</sup> E. Halkiadakis,<sup>173</sup> M. Heindl,<sup>173</sup> E. Hughes,<sup>173</sup> S. Kaplan,<sup>173</sup> R. Kunnawalkam Elayavalli,<sup>173</sup> S. Kyriacou,<sup>173</sup> A. Lath,<sup>173</sup> R. Montalvo,<sup>173</sup> K. Nash,<sup>173</sup> M. Osherson,<sup>173</sup> H. Saka,<sup>173</sup> S. Salur,<sup>173</sup> S. Schnetzer,<sup>173</sup> D. Sheffield,<sup>173</sup> S. Somalwar,<sup>173</sup> R. Stone,<sup>173</sup> S. Thomas,<sup>173</sup> P. Thomassen,<sup>173</sup> M. Walker,<sup>173</sup>

M. Foerster,<sup>174</sup> J. Heideman,<sup>174</sup> G. Riley,<sup>174</sup> K. Rose,<sup>174</sup> S. Spanier,<sup>174</sup> K. Thapa,<sup>174</sup> O. Bouhali,<sup>175,ppp</sup>  
A. Castaneda Hernandez,<sup>175,ppp</sup> A. Celik,<sup>175</sup> M. Dalchenko,<sup>175</sup> M. De Mattia,<sup>175</sup> A. Delgado,<sup>175</sup> S. Dildick,<sup>175</sup> R. Eusebi,<sup>175</sup>  
J. Gilmore,<sup>175</sup> T. Huang,<sup>175</sup> T. Kamon,<sup>175,qqq</sup> R. Mueller,<sup>175</sup> Y. Pakhotin,<sup>175</sup> R. Patel,<sup>175</sup> A. Perloff,<sup>175</sup> L. Perniè,<sup>175</sup>  
D. Rathjens,<sup>175</sup> A. Safonov,<sup>175</sup> A. Tatarinov,<sup>175</sup> K. A. Ulmer,<sup>175</sup> N. Akchurin,<sup>176</sup> J. Damgov,<sup>176</sup> F. De Guio,<sup>176</sup> C. Dragoiu,<sup>176</sup>  
P. R. Duerdo,<sup>176</sup> J. Faulkner,<sup>176</sup> E. Gurpinar,<sup>176</sup> S. Kunori,<sup>176</sup> K. Lamichhane,<sup>176</sup> S. W. Lee,<sup>176</sup> T. Libeiro,<sup>176</sup> T. Peltola,<sup>176</sup>  
S. Undleeb,<sup>176</sup> I. Volobouev,<sup>176</sup> Z. Wang,<sup>176</sup> S. Greene,<sup>177</sup> A. Gurrola,<sup>177</sup> R. Janjam,<sup>177</sup> W. Johns,<sup>177</sup> C. Maguire,<sup>177</sup>  
A. Melo,<sup>177</sup> H. Ni,<sup>177</sup> P. Sheldon,<sup>177</sup> S. Tuo,<sup>177</sup> J. Velkovska,<sup>177</sup> Q. Xu,<sup>177</sup> M. W. Arenton,<sup>178</sup> P. Barria,<sup>178</sup> B. Cox,<sup>178</sup>  
R. Hirosky,<sup>178</sup> A. Ledovskoy,<sup>178</sup> H. Li,<sup>178</sup> C. Neu,<sup>178</sup> T. Sinthuprasith,<sup>178</sup> X. Sun,<sup>178</sup> Y. Wang,<sup>178</sup> E. Wolfe,<sup>178</sup> F. Xia,<sup>178</sup>  
C. Clarke,<sup>179</sup> R. Harr,<sup>179</sup> P. E. Karchin,<sup>179</sup> J. Sturdy,<sup>179</sup> S. Zaleski,<sup>179</sup> D. A. Belknap,<sup>180</sup> J. Buchanan,<sup>180</sup> C. Caillol,<sup>180</sup>  
S. Dasu,<sup>180</sup> L. Dodd,<sup>180</sup> S. Duric,<sup>180</sup> B. Gomber,<sup>180</sup> M. Grothe,<sup>180</sup> M. Herndon,<sup>180</sup> A. Hervé,<sup>180</sup> U. Hussain,<sup>180</sup> P. Klabbers,<sup>180</sup>  
A. Lanaro,<sup>180</sup> A. Levine,<sup>180</sup> K. Long,<sup>180</sup> R. Loveless,<sup>180</sup> G. A. Pierro,<sup>180</sup> G. Polese,<sup>180</sup> T. Ruggles,<sup>180</sup> A. Savin,<sup>180</sup> N. Smith,<sup>180</sup>  
W. H. Smith,<sup>180</sup> D. Taylor,<sup>180</sup> and N. Woods<sup>180</sup>

(CMS Collaboration)

<sup>1</sup>*Yerevan Physics Institute, Yerevan, Armenia*<sup>2</sup>*Institut für Hochenergiephysik, Wien, Austria*<sup>3</sup>*Institute for Nuclear Problems, Minsk, Belarus*<sup>4</sup>*National Centre for Particle and High Energy Physics, Minsk, Belarus*<sup>5</sup>*Universiteit Antwerpen, Antwerpen, Belgium*<sup>6</sup>*Vrije Universiteit Brussel, Brussel, Belgium*<sup>7</sup>*Université Libre de Bruxelles, Bruxelles, Belgium*<sup>8</sup>*Ghent University, Ghent, Belgium*<sup>9</sup>*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*<sup>10</sup>*Université de Mons, Mons, Belgium*<sup>11</sup>*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*<sup>12</sup>*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*<sup>13a</sup>*Universidade Estadual Paulista, São Paulo, Brazil*<sup>13b</sup>*Universidade Federal do ABC, São Paulo, Brazil*<sup>14</sup>*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*<sup>15</sup>*University of Sofia, Sofia, Bulgaria*<sup>16</sup>*Beihang University, Beijing, China*<sup>17</sup>*Institute of High Energy Physics, Beijing, China*<sup>18</sup>*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*<sup>19</sup>*Universidad de Los Andes, Bogota, Colombia*<sup>20</sup>*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*<sup>21</sup>*University of Split, Faculty of Science, Split, Croatia*<sup>22</sup>*Institute Rudjer Boskovic, Zagreb, Croatia*<sup>23</sup>*University of Cyprus, Nicosia, Cyprus*<sup>24</sup>*Charles University, Prague, Czech Republic*<sup>25</sup>*Universidad San Francisco de Quito, Quito, Ecuador*<sup>26</sup>*Academy of Scientific Research and Technology of the Arab Republic of Egypt,  
Egyptian Network of High Energy Physics, Cairo, Egypt*<sup>27</sup>*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*<sup>28</sup>*Department of Physics, University of Helsinki, Helsinki, Finland*<sup>29</sup>*Helsinki Institute of Physics, Helsinki, Finland*<sup>30</sup>*Lappeenranta University of Technology, Lappeenranta, Finland*<sup>31</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*<sup>32</sup>*Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France*<sup>33</sup>*Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France*<sup>34</sup>*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*<sup>35</sup>*Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France*<sup>36</sup>*Georgian Technical University, Tbilisi, Georgia*<sup>37</sup>*Tbilisi State University, Tbilisi, Georgia*<sup>38</sup>*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*<sup>39</sup>*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*

- <sup>40</sup>RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany  
<sup>41</sup>Deutsches Elektronen-Synchrotron, Hamburg, Germany  
<sup>42</sup>University of Hamburg, Hamburg, Germany  
<sup>43</sup>Institut für Experimentelle Kernphysik, Karlsruhe, Germany  
<sup>44</sup>Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece  
<sup>45</sup>National and Kapodistrian University of Athens, Athens, Greece  
<sup>46</sup>University of Ioánnina, Ioánnina, Greece  
<sup>47</sup>MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary  
<sup>48</sup>Wigner Research Centre for Physics, Budapest, Hungary  
<sup>49</sup>Institute of Nuclear Research ATOMKI, Debrecen, Hungary  
<sup>50</sup>Institute of Physics, University of Debrecen, Debrecen, Hungary  
<sup>51</sup>Indian Institute of Science (IISc), Bangalore, India  
<sup>52</sup>National Institute of Science Education and Research, Bhubaneswar, India  
<sup>53</sup>Panjab University, Chandigarh, India  
<sup>54</sup>University of Delhi, Delhi, India  
<sup>55</sup>Saha Institute of Nuclear Physics, Kolkata, India  
<sup>56</sup>Indian Institute of Technology Madras, Madras, India  
<sup>57</sup>Bhabha Atomic Research Centre, Mumbai, India  
<sup>58</sup>Tata Institute of Fundamental Research-A, Mumbai, India  
<sup>59</sup>Tata Institute of Fundamental Research-B, Mumbai, India  
<sup>60</sup>Indian Institute of Science Education and Research (IISER), Pune, India  
<sup>61</sup>Institute for Research in Fundamental Sciences (IPM), Tehran, Iran  
<sup>62</sup>University College Dublin, Dublin, Ireland  
<sup>63a</sup>INFN Sezione di Bari, Bari, Italy  
<sup>63b</sup>Università di Bari, Bari, Italy  
<sup>63c</sup>Politecnico di Bari, Bari, Italy  
<sup>64a</sup>INFN Sezione di Bologna, Bologna, Italy  
<sup>64b</sup>Università di Bologna, Bologna, Italy  
<sup>65a</sup>INFN Sezione di Catania, Catania, Italy  
<sup>65b</sup>Università di Catania, Catania, Italy  
<sup>66a</sup>INFN Sezione di Firenze, Firenze, Italy  
<sup>66b</sup>Università di Firenze, Firenze, Italy  
<sup>67</sup>INFN Laboratori Nazionali di Frascati, Frascati, Italy  
<sup>68a</sup>INFN Sezione di Genova, Genova, Italy  
<sup>68b</sup>Università di Genova, Genova, Italy  
<sup>69a</sup>INFN Sezione di Milano-Bicocca, Milano, Italy  
<sup>69b</sup>Università di Milano-Bicocca, Milano, Italy  
<sup>70a</sup>INFN Sezione di Napoli, Roma, Italy  
<sup>70b</sup>Università di Napoli 'Federico II', Roma, Italy  
<sup>70c</sup>Università della Basilicata, Roma, Italy  
<sup>70d</sup>Università G. Marconi, Roma, Italy  
<sup>71a</sup>INFN Sezione di Padova, Trento, Italy  
<sup>71b</sup>Università di Padova, Trento, Italy  
<sup>71c</sup>Università di Trento, Trento, Italy  
<sup>72a</sup>INFN Sezione di Pavia, Pavia, Italy  
<sup>72b</sup>Università di Pavia, Pavia, Italy  
<sup>73a</sup>INFN Sezione di Perugia, Perugia, Italy  
<sup>73b</sup>Università di Perugia, Perugia, Italy  
<sup>74a</sup>INFN Sezione di Pisa, Pisa, Italy  
<sup>74b</sup>Università di Pisa, Pisa, Italy  
<sup>74c</sup>Scuola Normale Superiore di Pisa, Pisa, Italy  
<sup>75a</sup>INFN Sezione di Roma, Pisa, Italy  
<sup>75b</sup>Sapienza Università di Roma, Pisa, Italy  
<sup>76a</sup>INFN Sezione di Torino, Novara, Italy  
<sup>76b</sup>Università di Torino, Novara, Italy  
<sup>76c</sup>Università del Piemonte Orientale, Novara, Italy  
<sup>77a</sup>INFN Sezione di Trieste, Trieste, Italy  
<sup>77b</sup>Università di Trieste, Trieste, Italy  
<sup>78</sup>Kyungpook National University, Daegu, Korea  
<sup>79</sup>Chonbuk National University, Jeonju, Korea

- <sup>80</sup>*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
- <sup>81</sup>*Hanyang University, Seoul, Korea*
- <sup>82</sup>*Korea University, Seoul, Korea*
- <sup>83</sup>*Seoul National University, Seoul, Korea*
- <sup>84</sup>*University of Seoul, Seoul, Korea*
- <sup>85</sup>*Sungkyunkwan University, Suwon, Korea*
- <sup>86</sup>*Vilnius University, Vilnius, Lithuania*
- <sup>87</sup>*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
- <sup>88</sup>*Centro de Investigación y de Estudios Avanzados del IPN, Mexico City, Mexico*
- <sup>89</sup>*Universidad Iberoamericana, Mexico City, Mexico*
- <sup>90</sup>*Benemerita Universidad Autónoma de Puebla, Puebla, Mexico*
- <sup>91</sup>*Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico*
- <sup>92</sup>*University of Auckland, Auckland, New Zealand*
- <sup>93</sup>*University of Canterbury, Christchurch, New Zealand*
- <sup>94</sup>*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
- <sup>95</sup>*National Centre for Nuclear Research, Swierk, Poland*
- <sup>96</sup>*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
- <sup>97</sup>*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
- <sup>98</sup>*Joint Institute for Nuclear Research, Dubna, Russia*
- <sup>99</sup>*Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia*
- <sup>100</sup>*Institute for Nuclear Research, Moscow, Russia*
- <sup>101</sup>*Institute for Theoretical and Experimental Physics, Moscow, Russia*
- <sup>102</sup>*Moscow Institute of Physics and Technology, Moscow, Russia*
- <sup>103</sup>*National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia*
- <sup>104</sup>*P.N. Lebedev Physical Institute, Moscow, Russia*
- <sup>105</sup>*Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia*
- <sup>106</sup>*Novosibirsk State University (NSU), Novosibirsk, Russia*
- <sup>107</sup>*State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia*
- <sup>108</sup>*University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia*
- <sup>109</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- <sup>110</sup>*Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>111</sup>*Universidad de Oviedo, Oviedo, Spain*
- <sup>112</sup>*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- <sup>113</sup>*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- <sup>114</sup>*Paul Scherrer Institut, Villigen, Switzerland*
- <sup>115</sup>*Institute for Particle Physics, ETH Zurich, Zurich, Switzerland*
- <sup>116</sup>*Universität Zürich, Zurich, Switzerland*
- <sup>117</sup>*National Central University, Chung-Li, Taiwan*
- <sup>118</sup>*National Taiwan University (NTU), Taipei, Taiwan*
- <sup>119</sup>*Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand*
- <sup>120</sup>*Cukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
- <sup>121</sup>*Middle East Technical University, Physics Department, Ankara, Turkey*
- <sup>122</sup>*Bogazici University, Istanbul, Turkey*
- <sup>123</sup>*Istanbul Technical University, Istanbul, Turkey*
- <sup>124</sup>*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine*
- <sup>125</sup>*National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine*
- <sup>126</sup>*University of Bristol, Bristol, United Kingdom*
- <sup>127</sup>*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- <sup>128</sup>*Imperial College, London, United Kingdom*
- <sup>129</sup>*Brunel University, Uxbridge, United Kingdom*
- <sup>130</sup>*Baylor University, Waco, Texas, USA*
- <sup>131</sup>*Catholic University of America, Washington DC, USA*
- <sup>132</sup>*The University of Alabama, Tuscaloosa, Alabama, USA*
- <sup>133</sup>*Boston University, Boston, Massachusetts, USA*
- <sup>134</sup>*Brown University, Providence, Rhode Island, USA*
- <sup>135</sup>*University of California, Davis, Davis, USA*
- <sup>136</sup>*University of California, Los Angeles, California, USA*
- <sup>137</sup>*University of California, Riverside, Riverside, USA*
- <sup>138</sup>*University of California, San Diego, La Jolla, USA*
- <sup>139</sup>*University of California, Santa Barbara - Department of Physics, Santa Barbara, USA*



- <sup>140</sup>*California Institute of Technology, Pasadena, California, USA*
- <sup>141</sup>*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- <sup>142</sup>*University of Colorado Boulder, Boulder, Colorado, USA*
- <sup>143</sup>*Cornell University, Ithaca, New York, USA*
- <sup>144</sup>*Fairfield University, Fairfield, Connecticut, USA*
- <sup>145</sup>*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- <sup>146</sup>*University of Florida, Gainesville, Florida, USA*
- <sup>147</sup>*Florida International University, Miami, Florida, USA*
- <sup>148</sup>*Florida State University, Tallahassee, Florida, USA*
- <sup>149</sup>*Florida Institute of Technology, Melbourne, Florida, USA*
- <sup>150</sup>*University of Illinois at Chicago (UIC), Chicago, Illinois, USA*
- <sup>151</sup>*The University of Iowa, Iowa City, Iowa, USA*
- <sup>152</sup>*Johns Hopkins University, Baltimore, Maryland, USA*
- <sup>153</sup>*The University of Kansas, Lawrence, Kansas, USA*
- <sup>154</sup>*Kansas State University, Manhattan, Kansas, USA*
- <sup>155</sup>*Lawrence Livermore National Laboratory, Livermore, California, USA*
- <sup>156</sup>*University of Maryland, College Park, Maryland, USA*
- <sup>157</sup>*Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*
- <sup>158</sup>*University of Minnesota, Minneapolis, Minnesota, USA*
- <sup>159</sup>*University of Mississippi, Oxford, Mississippi, USA*
- <sup>160</sup>*University of Nebraska-Lincoln, Lincoln, Nebraska, USA*
- <sup>161</sup>*State University of New York at Buffalo, Buffalo, New York, USA*
- <sup>162</sup>*Northeastern University, Boston, Massachusetts, USA*
- <sup>163</sup>*Northwestern University, Evanston, Illinois, USA*
- <sup>164</sup>*University of Notre Dame, Notre Dame, Indiana, USA*
- <sup>165</sup>*The Ohio State University, Columbus, Ohio, USA*
- <sup>166</sup>*Princeton University, Princeton, New Jersey, USA*
- <sup>167</sup>*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
- <sup>168</sup>*Purdue University, West Lafayette, Indiana, USA*
- <sup>169</sup>*Purdue University Northwest, Hammond, Indiana, USA*
- <sup>170</sup>*Rice University, Houston, Texas, USA*
- <sup>171</sup>*University of Rochester, Rochester, New York, USA*
- <sup>172</sup>*The Rockefeller University, New York, New York, USA*
- <sup>173</sup>*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
- <sup>174</sup>*University of Tennessee, Knoxville, Tennessee, USA*
- <sup>175</sup>*Texas A&M University, College Station, Texas, USA*
- <sup>176</sup>*Texas Tech University, Lubbock, Texas, USA*
- <sup>177</sup>*Vanderbilt University, Nashville, Tennessee, USA*
- <sup>178</sup>*University of Virginia, Charlottesville, Virginia, USA*
- <sup>179</sup>*Wayne State University, Detroit, Michigan, USA*
- <sup>180</sup>*University of Wisconsin - Madison, Madison, Wisconsin, USA*

<sup>a</sup>Also at Vienna University of Technology, Vienna, Austria.

<sup>b</sup>Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China.

<sup>c</sup>Also at Universidade Estadual de Campinas, Campinas, Brazil.

<sup>d</sup>Also at Universidade Federal de Pelotas, Pelotas, Brazil.

<sup>e</sup>Also at Université Libre de Bruxelles, Bruxelles, Belgium.

<sup>f</sup>Also at Joint Institute for Nuclear Research, Dubna, Russia.

<sup>g</sup>Also at Suez University, Suez, Egypt.

<sup>h</sup>Also at British University in Egypt, Cairo, Egypt.

<sup>i</sup>Also at Fayoum University, El-Fayoum, Egypt.

<sup>j</sup>Also at Helwan University, Cairo, Egypt.

<sup>k</sup>Also at Université de Haute Alsace, Mulhouse, France.

<sup>l</sup>Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.

<sup>m</sup>Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.

<sup>n</sup>Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

<sup>o</sup>Also at University of Hamburg, Hamburg, Germany.

<sup>p</sup>Also at Brandenburg University of Technology, Cottbus, Germany.

<sup>q</sup>Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

<sup>r</sup>Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.

- <sup>s</sup> Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
- <sup>t</sup> Also at IIT Bhubaneswar, Bhubaneswar, India.
- <sup>u</sup> Also at Institute of Physics, Bhubaneswar, India.
- <sup>v</sup> Also at University of Visva-Bharati, Santiniketan, India.
- <sup>w</sup> Also at University of Ruhuna, Matara, Sri Lanka.
- <sup>x</sup> Also at Isfahan University of Technology, Isfahan, Iran.
- <sup>y</sup> Also at Yazd University, Yazd, Iran.
- <sup>z</sup> Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.
- <sup>aa</sup> Also at Università degli Studi di Siena, Siena, Italy.
- <sup>bb</sup> Also at Purdue University, West Lafayette, USA.
- <sup>cc</sup> Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia.
- <sup>dd</sup> Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia.
- <sup>ee</sup> Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico.
- <sup>ff</sup> Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
- <sup>gg</sup> Also at Institute for Nuclear Research, Moscow, Russia.
- <sup>hh</sup> Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia.
- <sup>ii</sup> Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- <sup>jj</sup> Also at University of Florida, Gainesville, USA.
- <sup>kk</sup> Also at P.N. Lebedev Physical Institute, Moscow, Russia.
- <sup>ll</sup> Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
- <sup>mm</sup> Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- <sup>nn</sup> Also at INFN Sezione di Roma, Sapienza Università di Roma, Rome, Italy.
- <sup>oo</sup> Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- <sup>pp</sup> Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.
- <sup>qq</sup> Also at National and Kapodistrian University of Athens, Athens, Greece.
- <sup>rr</sup> Also at Riga Technical University, Riga, Latvia.
- <sup>ss</sup> Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- <sup>tt</sup> Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- <sup>uu</sup> Also at Istanbul University, Faculty of Science, Istanbul, Turkey.
- <sup>vv</sup> Also at Istanbul Aydin University, Istanbul, Turkey.
- <sup>ww</sup> Also at Mersin University, Mersin, Turkey.
- <sup>xx</sup> Also at Cag University, Mersin, Turkey.
- <sup>yy</sup> Also at Piri Reis University, Istanbul, Turkey.
- <sup>zz</sup> Also at Gaziosmanpasa University, Tokat, Turkey.
- <sup>aaa</sup> Also at Adiyaman University, Adiyaman, Turkey.
- <sup>bbb</sup> Also at Izmir Institute of Technology, Izmir, Turkey.
- <sup>ccc</sup> Also at Necmettin Erbakan University, Konya, Turkey.
- <sup>ddd</sup> Also at Marmara University, Istanbul, Turkey.
- <sup>eee</sup> Also at Kafkas University, Kars, Turkey.
- <sup>fff</sup> Also at Istanbul Bilgi University, Istanbul, Turkey.
- <sup>ggg</sup> Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- <sup>hhh</sup> Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- <sup>iii</sup> Also at Instituto de Astrofísica de Canarias, La Laguna, Spain.
- <sup>jjj</sup> Also at Utah Valley University, Orem, USA.
- <sup>kkk</sup> Also at Beykent University.
- <sup>lll</sup> Also at Bingol University, Bingol, Turkey.
- <sup>mmm</sup> Also at Erzincan University, Erzincan, Turkey.
- <sup>nnn</sup> Also at Sinop University, Sinop, Turkey.
- <sup>ooo</sup> Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- <sup>ppp</sup> Also at Texas A&M University at Qatar, Doha, Qatar.
- <sup>qqq</sup> Also at Kyungpook National University, Daegu, Korea.